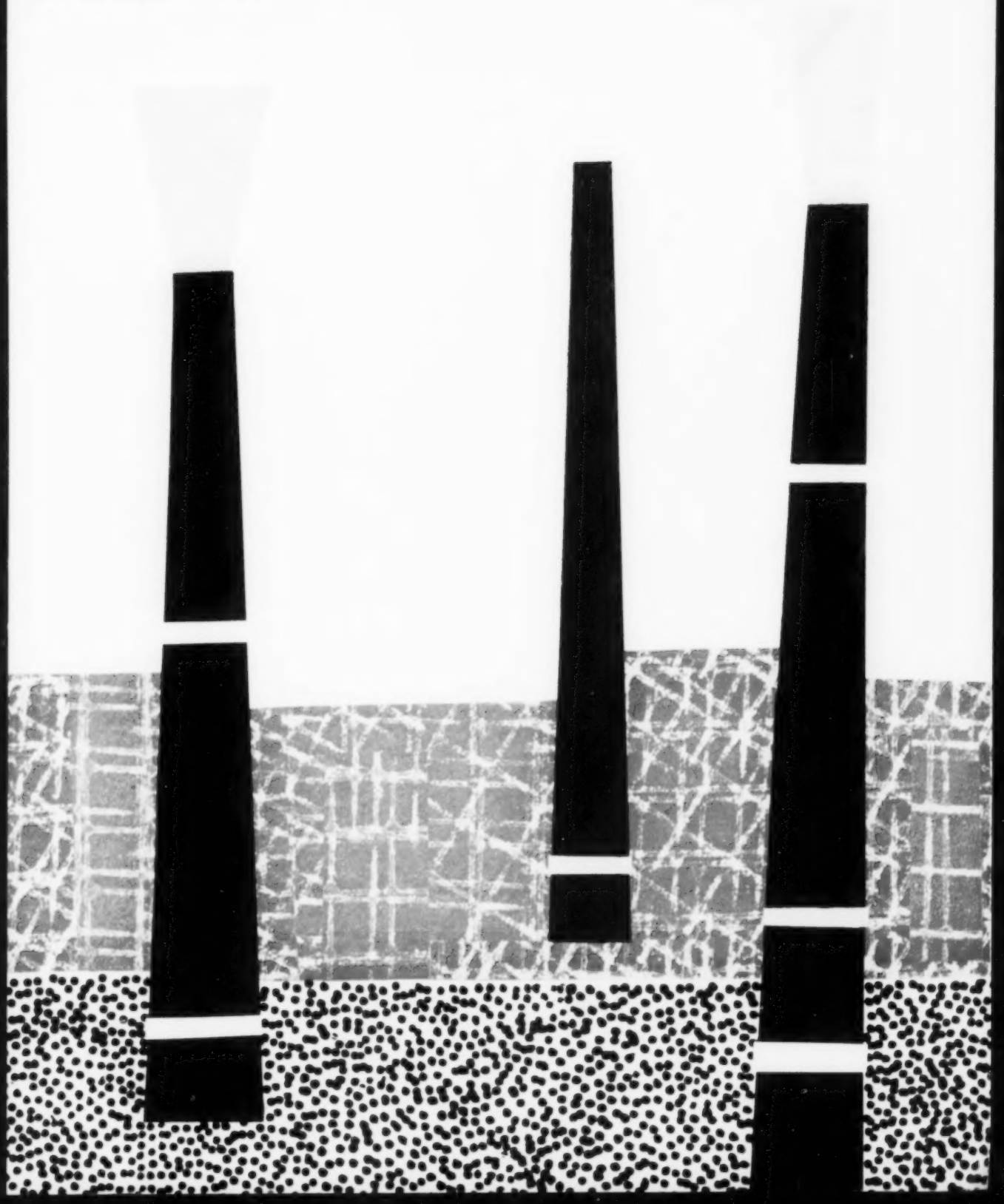
JOURNAL OF

METALS

SEPTEMBER 1957



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JOURNAL OF

METALS

VOL. 9, NO. 9

SEPTEMBER 1957

Published to provide a continuing, authoritative, and up-to-date record of technological, engineering, and economic progress in all branches of the industry by the Metallurgical Society, American Institute of Mining, Metallurgical, and Petroleum Engineers, Inc., 29 West 39th Street, New York 18, N. Y.

COVER

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(Continued on page 1088)

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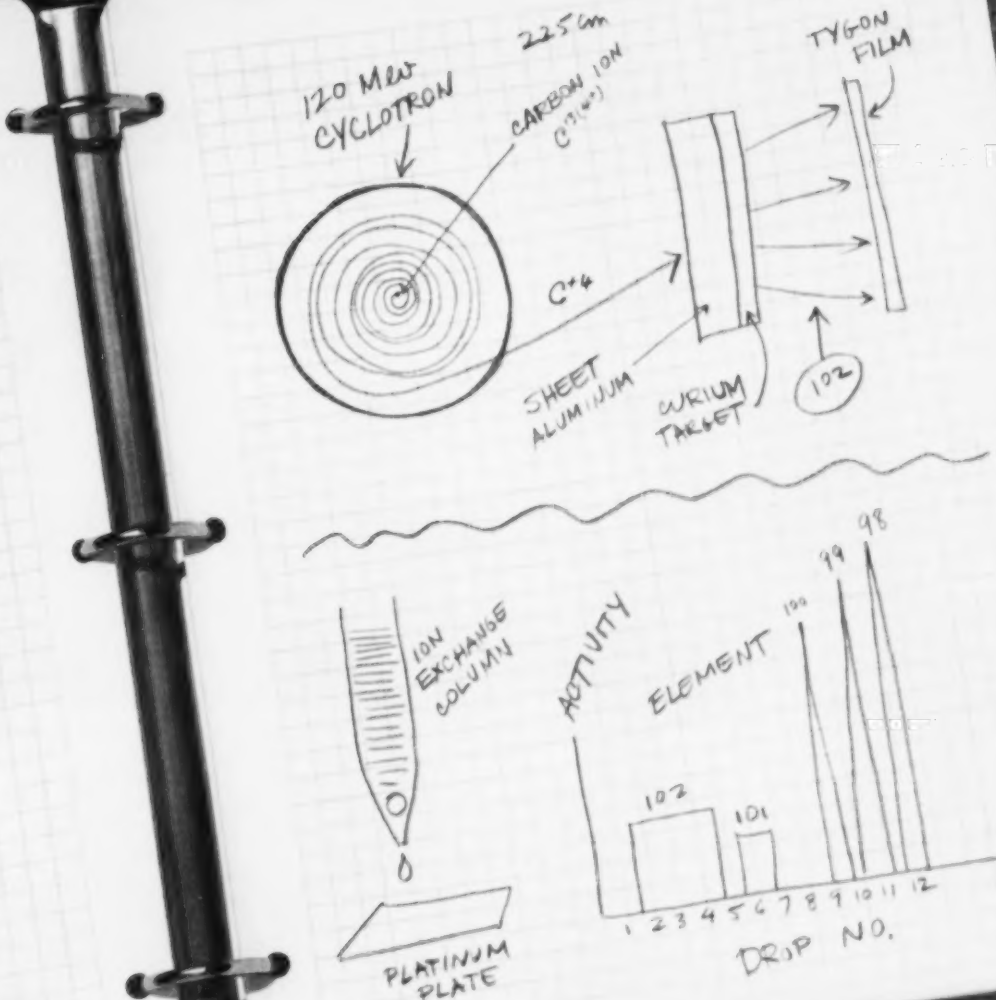

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Personnel

(Continued from page 1086)

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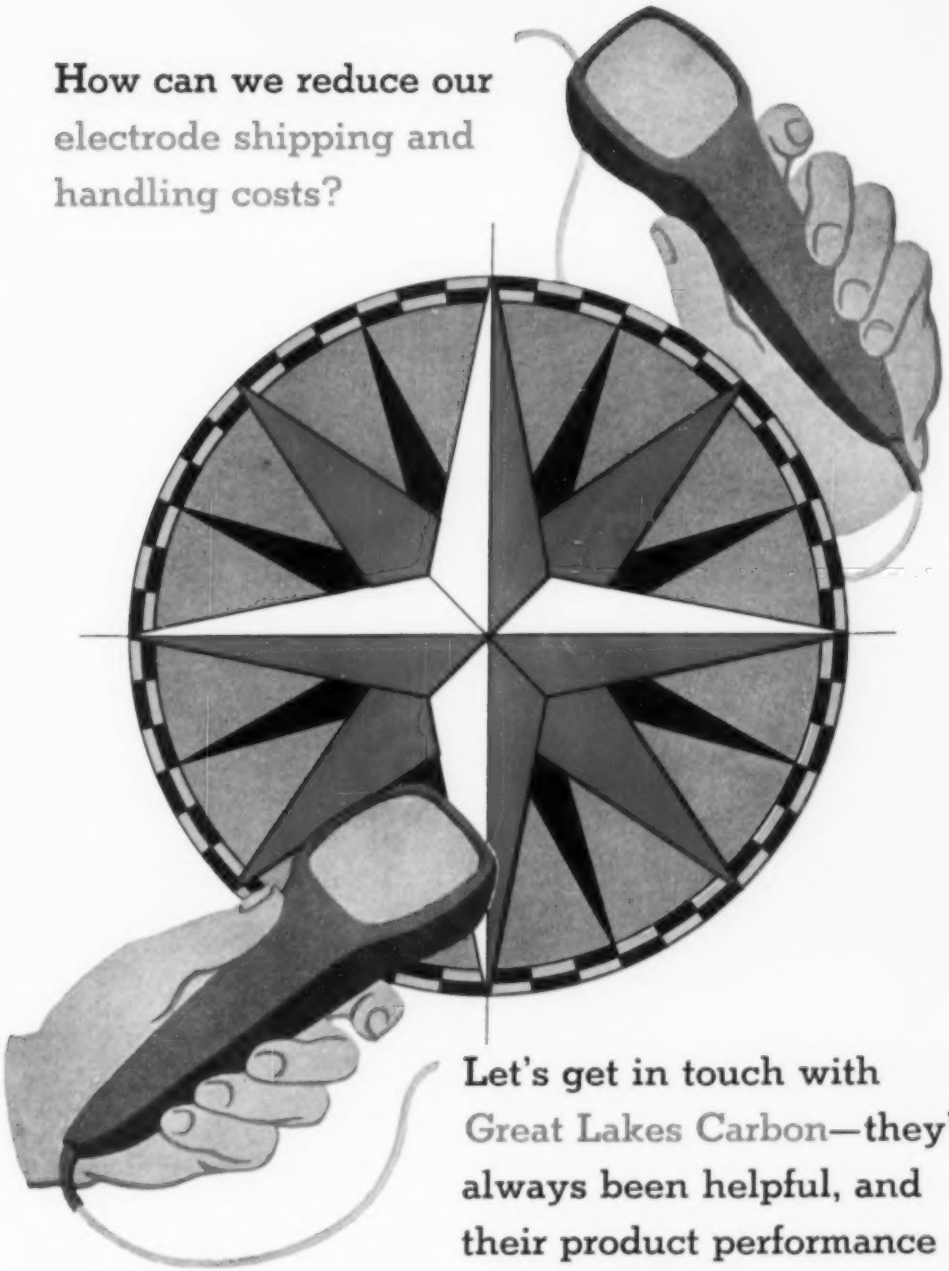

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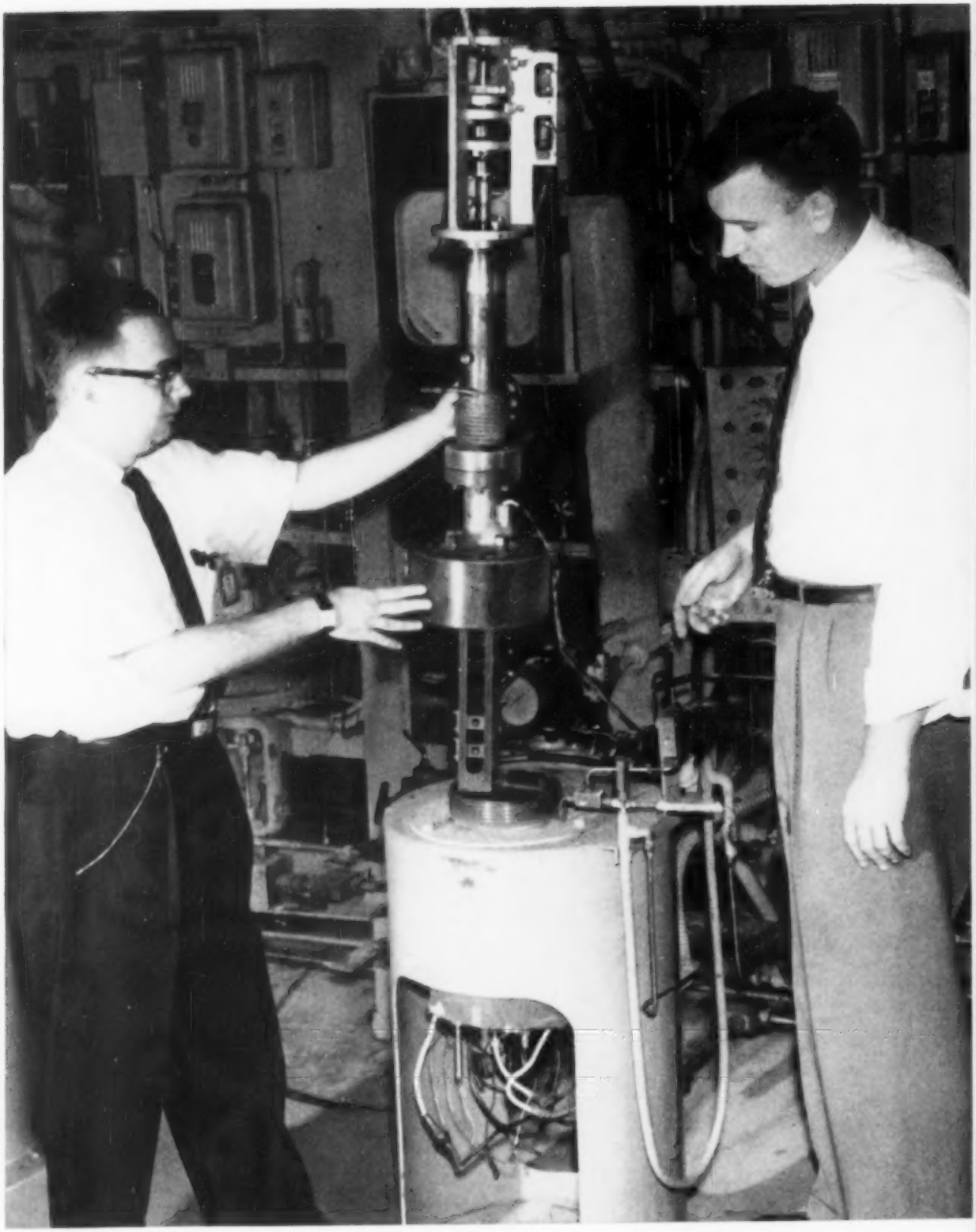

Dr. Eric Rau and James Alger, Bettis engineers cooperating on different aspects of this program, are discussing details of a preliminary corrosion fatigue test. Note two specimens mounted on a knife edge in the machine. The entire assembly is attached to the head of an autoclave for immersion in water at 600° Fahrenheit. Dr. Rau received his Ph.D. in physical chemistry from New York University in 1955. Mr. Alger obtained his Master's degree in metallurgy from the University of Washington in 1955.

MATERIALS ENGINEERING

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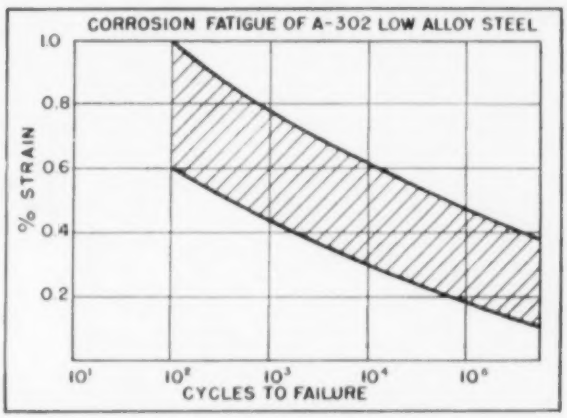

The cross-hatching in the graph indicates the strain range to be investigated. Fatigue specimens will be strain cycled in primary coolant water at 600° F. In each experiment five points on the strain vs cycles-to-failure curve will be obtained.

From the results shown by the strain versus cycle-to-failure diagrams, reactor designers can better determine the applicability of these materials to new designs.

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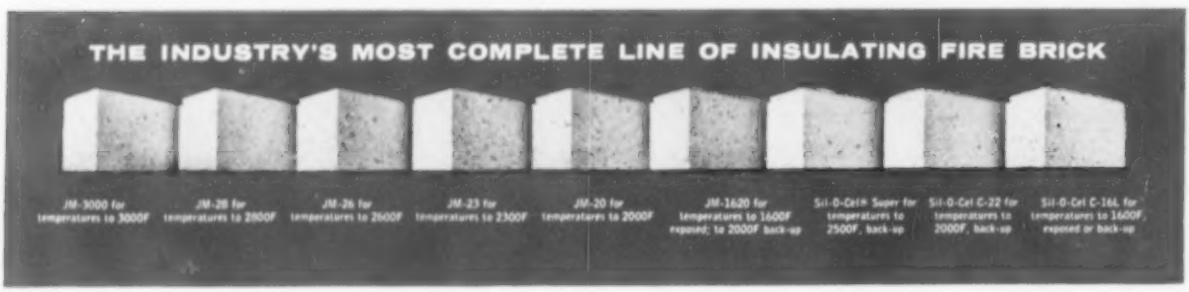
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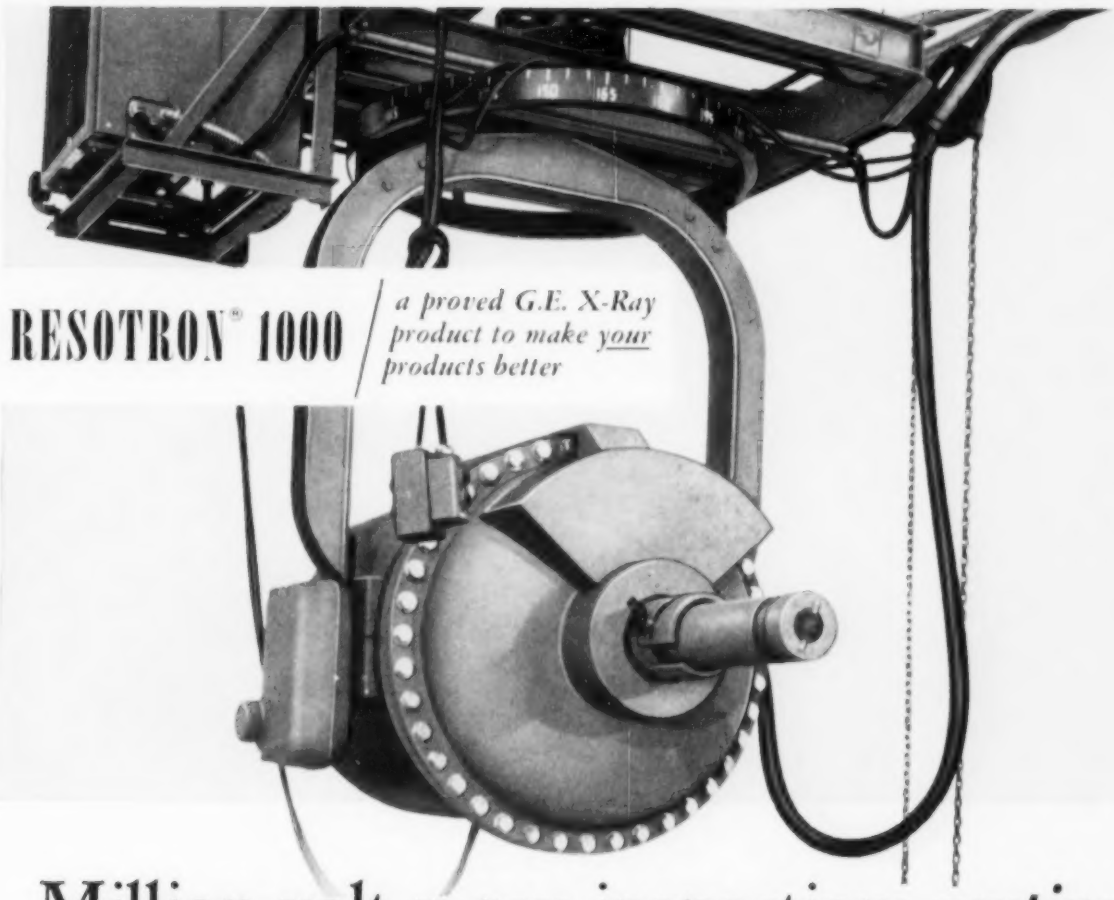
Mining Year Book, 1957, compiled by Walter E. Skinner, *Walter E. Skinner*, 20 Cepthall Ave., and *Financial Times*, 72 Coleman St., London E.C.2, England, 825 pp., $7.00, 1957—This book features complete and up-to-date particulars concerning mining companies operating in all parts of the world. Gold, silver, copper, tin, lead, zinc, diamond, uranium, and other mines; collieries; exploration and mining finance companies are listed in alphabetical order. Information given for each company includes the names of directors and other officials, date of incorporation, seat of operations, description of property, plant erected or in process of completion, present working results, ore reserves, details of capital, dividends paid, and the financial position as disclosed by the latest accounts. Highest and lowest prices of the shares are quoted for the last three years. Other indexes included in the yearbook give the names, addresses, and company affiliations of over 1200 mining engineers; world production tables of gold and base metals; and a buyers' guide, listing firms supplying mine plant equipment, accessories, etc. •

Handbook of Chemistry and Physics, *The Chemical Rubber Co.*, 2310 Superior Ave., Cleveland 14, Ohio, over 3000 pp., $12.00, 1957.—This volume is a complete reference of the sciences: chemistry, physics, and mathematics, that is continuously revised and annually published. This 38th edition is divided into five indexed sections consisting of mathematical tables, properties and physical constants, general chemical tables, heat and hygrometry, and quantities and units. It gives interpretations of factual data of major importance to scientific work and study. Over 100 pp. of new information have been added to this edition. •

Minerals Yearbook, 1953, Area Reports, Volume III, by the staff of the U. S. Bureau of Mines, *Superintendent of Documents*, U. S. Government Printing Office, Washington 25, D. C., $3.75, 1133 pp., 1956.—*Yearbook* material has increased to the point where it is impractical to publish it under one cover. This third volume completes the Yearbook for 1953. Volume I, *Metals and Minerals (Except Fuels)* ($4.00) contains

(Continued on page 1100)



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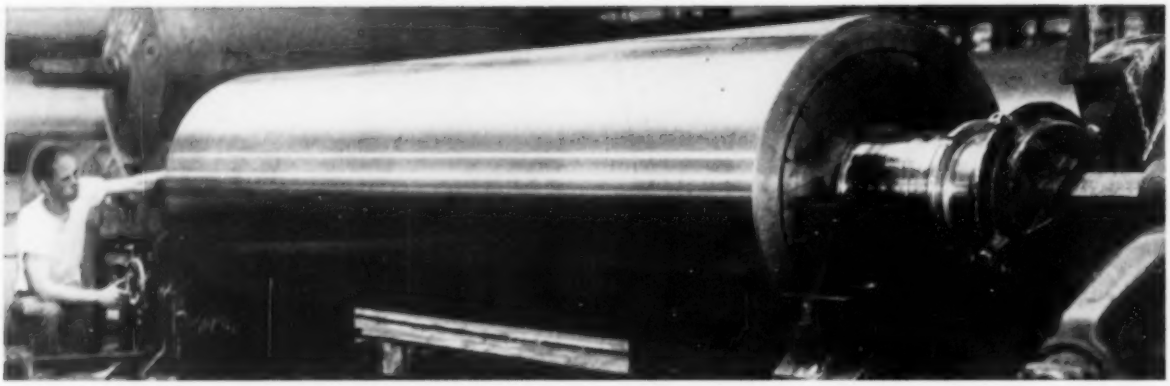
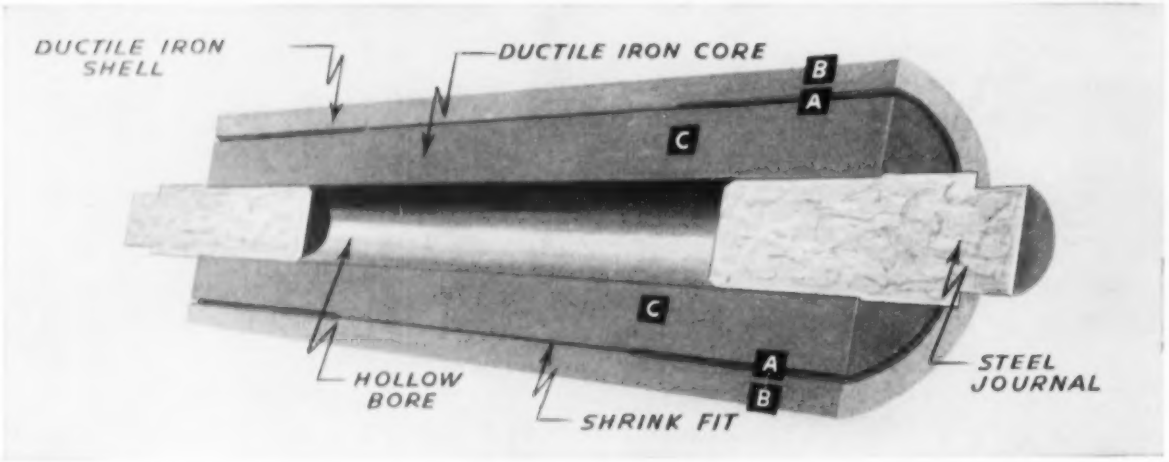


Unusual roll is built without a crown...



Unique design based on high rigidity of ductile cast iron

"Crowning" – designing paper machine rolls with a midriff bulge – compensates for deflection, and helps maintain uniform "nip" pressure between a pair of rolls. But crowning requires costly machining operations and reduces the life of felt roll covers.

To eliminate this problem, Black-Clawson engineers took advantage of the high rigidity of ductile iron – it has a modulus of 24 million. That means it's stiff enough to resist deflection even under heavy loads.

In the crownless press roll shown above, the stiff ductile iron core supports the "nip" load plus the entire roll weight. The open space at (A) allows the core to deflect while the working face of the roll (B) remains almost perfectly flat – within .003 inch. Standard crowned rolls vary from zero to as much as .015 inch through the working range of the "nip" load.

Ductile iron also has the fatigue resistance to withstand the continuously alternating stresses produced at (C) as the roll rotates.

Ductile irons (there are 7 types available commercially) create new design opportunities by combining cast iron's *process* advantages with many of steel's *product* advantages: excellent castability and machinability *plus* high strength, wear resistance, and rigidity without brittleness.

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Zinc, Blast Furnace Produced

Successful completion of 25 years of work by the Imperial Smelting Corp. is the operation of two zinc blast furnaces at Avonmouth, England. This marks a tremendous stride forward, for blast furnace smelting of zinc means large-scale output of commercially pure metal from impure raw materials which could not be treated by previous methods. Full details of the new process have been given in a paper to the Institute of Mining and Metallurgy—London—by S. W. K. Morgan.

—oxidation of vapor a major problem

The primary problem to be solved was that of condensing zinc from a large volume of combustion gases with a relatively low concentration of zinc vapor and a considerable amount of carbon dioxide. Special precautions had to be taken to avoid reoxidation of zinc—the whole furnace charge and gases must be maintained above the reoxidation temperature.

—condensation by liquid lead

The key to the development of a successful condenser was the discovery that the use of liquid lead as a circulating medium for heat transfer and collection of zinc enabled oxidation of zinc vapor to be minimized.

—the two blast furnaces

The furnaces have a water-jacketed bottom section, with water-cooled tuyeres, and a brick-lined top shaft. The small furnace has 16 tuyeres and a hearth area of 55 sq ft; the larger, 20 tuyeres and an area of 69 sq ft. Even the larger—40 tpd—is judged to be considerably smaller than optimum. The hot zinc-containing gases are withdrawn above the furnace charge; the furnace top is totally enclosed; and batch charges are introduced via a double bell system.

—two condensers on each furnace

The condensers have three vertical shaft rotors in series, dipping successive stages of the lead pool in the bottom of the condenser. This creates an intense shower of lead droplets which cools the gas to a temperature near that of lead. The gas from the condenser—containing some 5 pct of the zinc entering—is scrubbed, first in a spray tower, then in Theissen-type disintegrators. Lead is pumped at the rate of 300 to 400 tons per hr through a closed circuit comprising: one condenser, a pump chamber, a long water-cooled launder, and a separation bath in which the liquid zinc separates as a top liquid layer. The zinc overflows continuously into a bath for reheating and for treatment with sodium to remove arsenic.

—Prime Western Grade zinc produced

Slag, matte, and bullion are periodically tapped from the furnace. Zinc content of the slag can be maintained between 2 and 3 pct. The fuel used is coke, typically 3-in. lump size. A charge free from fines and hard enough to prevent excessive breakdown in the furnace is called for. Fluxing materials can be incorporated in the sinter or added separately.

—useful for lead-zinc concentrates

This process has opened up the possibility of recovering directly both lead and zinc as metals from those lead-zinc ores in which the components cannot be completely separated by froth flotation. Lead is obtained as bullion, and iron is rejected in the slag. Copper can be collected with the bullion or as matte.

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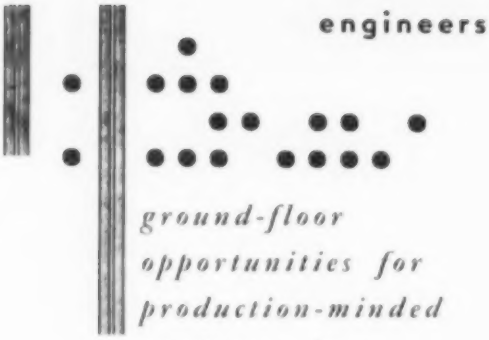

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Books

(Continued from page 1094)

chapters on mineral commodities, a chapter reviewing these industries, a statistical summary and recapitulation, and chapters on mining technology, metallurgical technology, and employment and injuries. Volume II, *Fuels* ($2.25) consists of chapters on each mineral-fuel commodity, as well as chapters reviewing the industry as a whole, a statistical summary, and an employment and injury presentation. Volume III is made up of chapters covering each of the 48 states, plus chapters on Alaska, the Territories and island possessions in the Pacific and the Caribbean, including the Canal Zone. It also has a chapter recapitulating its statistics in summary form on a regional basis and another presenting employment and injury data regionally. Volume III, 1953, is essentially a reissue of the material covered in Volume III, 1952.

Year Book of the American Bureau of Metals Statistics, 36th annual issue for year 1956, *American Bureau of Metal Statistics*, 50 Broadway, New York 4, N. Y., 133 pp. $3.00 postpaid in U. S. and Canada, $3.25 to other countries, 1957.—This annual publication covers, from a statistical basis, the economy of nonferrous metals on a world-wide scale. Major nonferrous metals covered are copper, lead, zinc, aluminum, gold and silver, tin, antimony, cadmium, magnesium, cobalt, nickel, molybdenum, and platinum. Some of the pertinent data included in this volume cover statistics of production, consumption, operations, imports and exports of the U. S. and the United Kingdom, metallurgical plants and capacities, and other economic information. •

Boron, Calcium, Columbium, and Zirconium in Iron and Steel, by R. A. Grange, F. J. Shortsleeve, D. C. Hilty, W. O. Binder, G. T. Motock, and C. M. Offenhauer, *John Wiley & Sons Inc.*, 533 pp., $14.00, 1957.—This is a collection of four short monographs on four of the elements used as alloying metals with iron and steel: boron, calcium, columbium

(Continued on page 1106)

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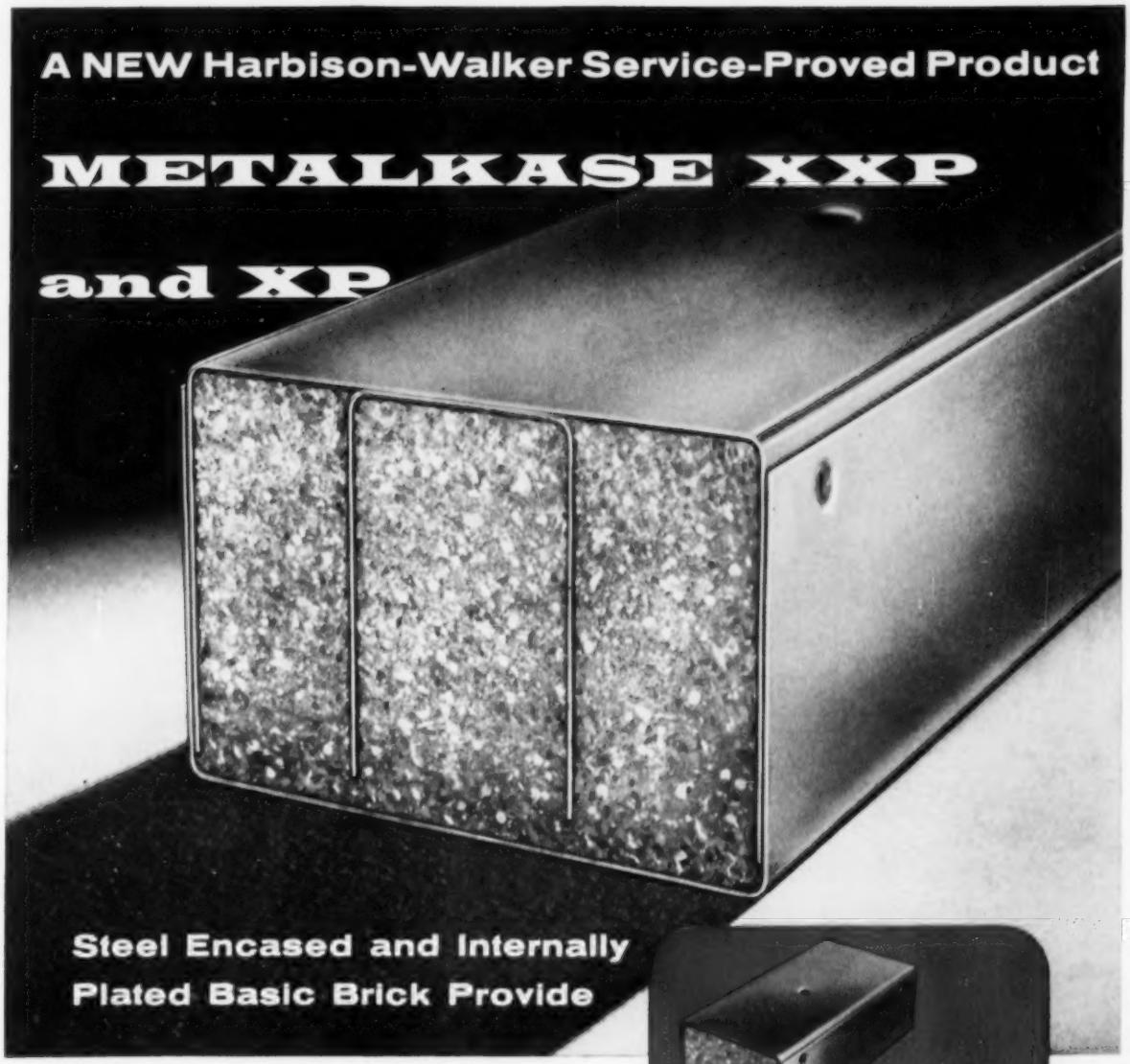

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- **greater spalling resistance**
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METALKASE XXP are chemically bonded basic brick with two internal plates, formed under high pressure, and are furnished in standard sizes, suspended arch and other shapes. They are available in various compositions. In the illustration the METALKASE XXP brick is cut to show the plated construction. These plates extend through the length of the brick.

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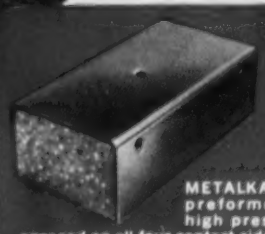
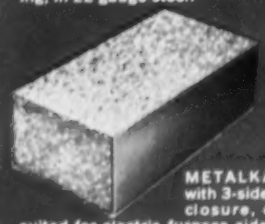
Extensive use in service clearly demonstrates the superior spalling resistance of the internally plated brick, and as the result of improved stress relief, appreciably reduced tendency to peel.



METALKASE brick, preformed under high pressure and encased on all four contact sides by welding, in 22 gauge steel.



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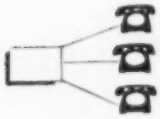

Wave filter. Precisely separates bands of frequencies. Provided major key to economical sharing of the same wires by many voices or radio programs. Indispensable control tool in radio, television and radar.

Negative feedback amplifier. Provides distortionless and stable amplification. Made possible the enormous, precisely controlled amplification needed in long distance telephone calls. The principle is now basic in high-quality amplifiers for radio, TV and high-fidelity reproduction.

Quartz crystal. Standard super-accurate quartz crystal oscillator developed for frequency controls in radio telephony. Has also become the standard control for clocks in world's astronomical laboratories.

Coaxial cable system. Hollow tube with a central conductor was developed to transmit hundreds of voices simultaneously. Now also provides long distance carrier for TV in partnership with microwave beams.

Transistor. Tiny solid-state device uses extremely small amounts of power to amplify signals. Makes possible electronic telephone switching and much smaller hearing aids, radios, TV sets and electronic computers.

Dial system "brain and memory." Takes over your call and sees that you are connected in the best and quickest way. Newest example: Direct Distance Dialing from home telephones to any part of the nation.

Waveguide. Hollow conductor transmits high-frequency waves. From this came the "pipe" circuits that are essential to radar and very short-wave radio communications.

Microwaves. Bell Laboratories developed long distance microwave transmission. It operates by focusing radio beams from station to station, carries cross-country telephony and TV.

Radio astronomy. This great new science began in the study of radio interference at Bell Laboratories . . . with the tremendous discovery that radio waves emanate from the stars.

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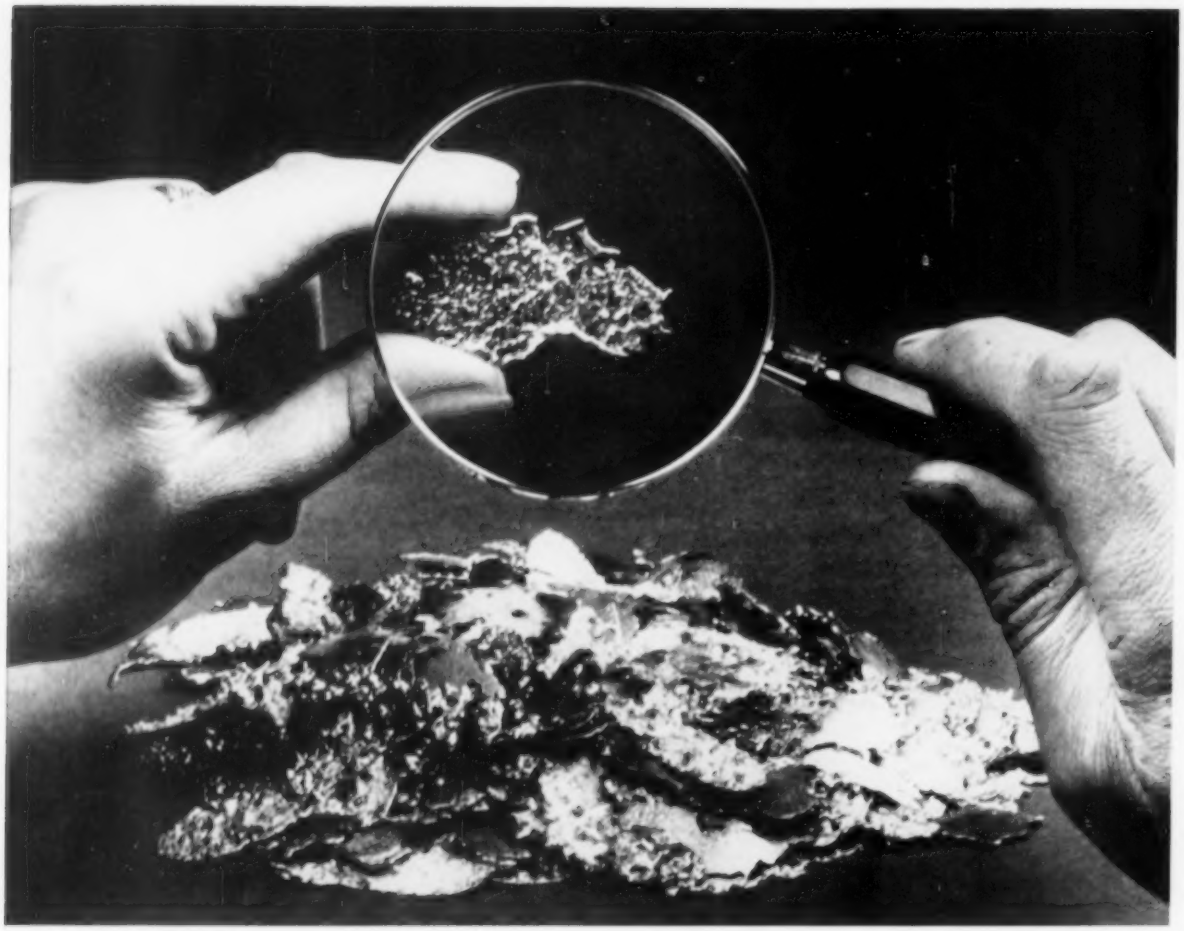

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Books

(Continued from page 1100)

(plus tantalum), and zirconium. These monographs were written by authorities in the field and collect in a single binding all the scattered published and unpublished data on these important alloying metals. The book eases the burden of research placed on the engineer and metallurgist by making available to him accurate information in a clear and concise form. •

The Science of Engineering Materials, edited by J. E. Goldman, *John Wiley & Sons Inc.*, 528 pp., $12.00, 1957.—Why do materials behave as they do? This book attempts to answer this question by applying basic principles of solid state physics to the explanation of properties of materials. The book is the work of a number of the outstanding scientists in a variety of physical and engineering fields. In defining the actual molecular makeup of materials, they explain and interpret, qualitatively, the properties of metals, alloys, semiconductors, cements, polymers, and glasses. •

Elements Of Pure and Applied Mathematics, by Harry Lass, *McGraw-Hill Book Co. Inc.*, 491 pp., $7.50, 1957.—A thorough treatment is given of the various subjects in classical mathematics which are most useful to the engineer and physicist. It covers and illuminates most of the subjects that an undergraduate math major will encounter in his course work, and gives him good preparation for the use of applied mathematics. A considerable number of examples are worked out in detail, and problems follow each section. •

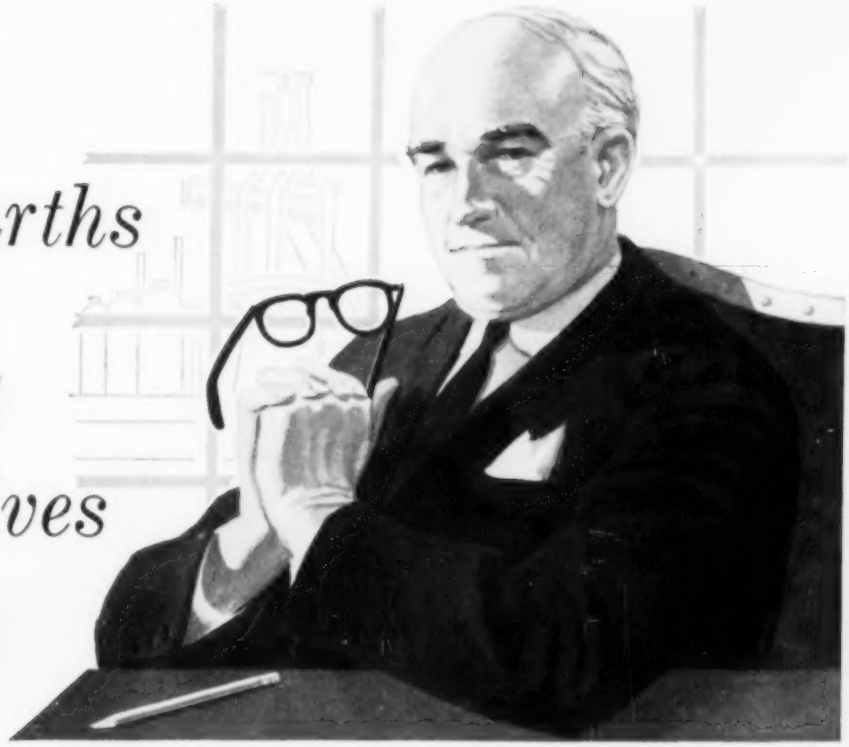
Heat and Thermodynamics, 4th edition, by Mark W. Zemansky, *McGraw-Hill Book Co. Inc.*, 484 pp., $7.50, 1957.—Fundamental ideas of temperature, work, internal energy, heat, reversibility, and entropy are given, with examples and applications mostly to ideal gases. The properties of chemical, linear, surface, electric, and magnetic systems are introduced in the beginning and used in general discussions instead of being reserved for special treatment at the end. Methods of measurement are explained throughout the book and actual numerical data are given in numerous tables and graphs. •

The Demand and Supply of Scientific Personnel, by David M. Blank and George J. Stigler, *National Bureau of Economic Research*, 261 Madison Ave., New York 16, N. Y., 198 pp., $4.00, 1957.—Drs. Blank and Stigler have investigated ways to explain and eventually to predict the demand and supply of technological and professional workers, under a

(Continued on page 1109)

Rare Earths and Steel Executives

?



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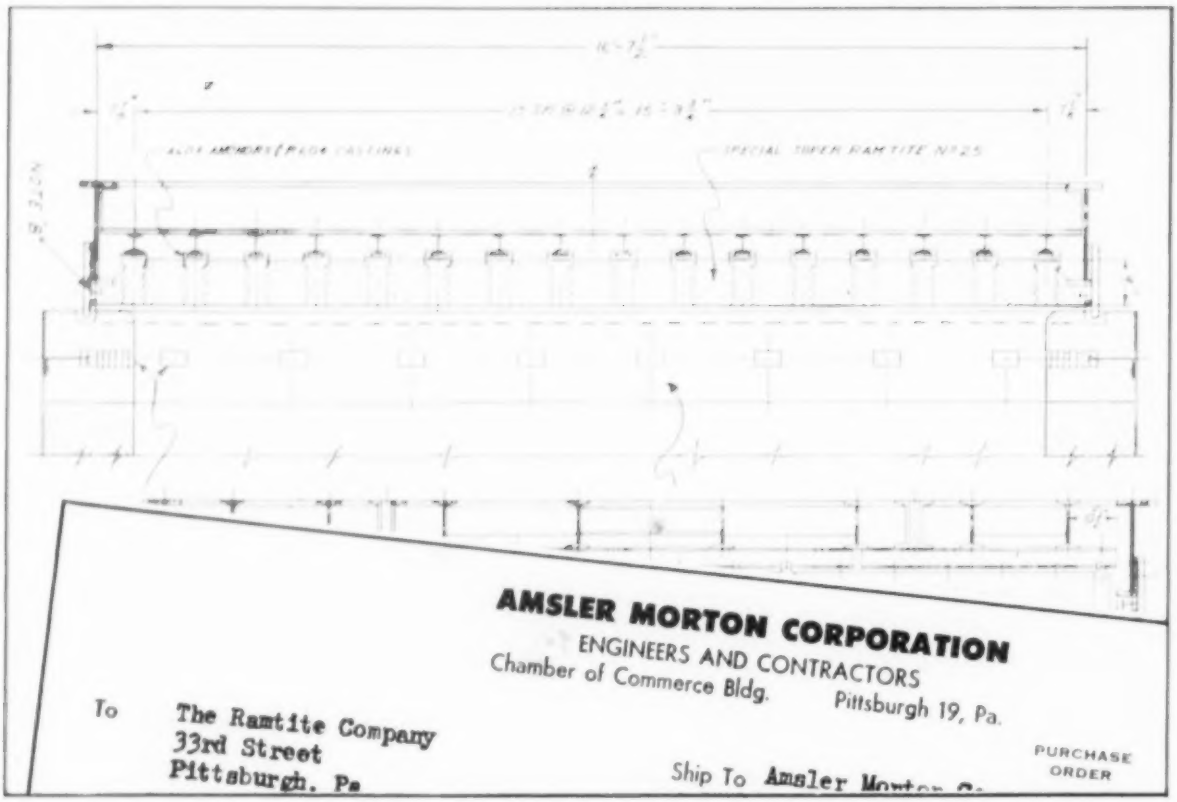

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Books

(Continued from page 1106)

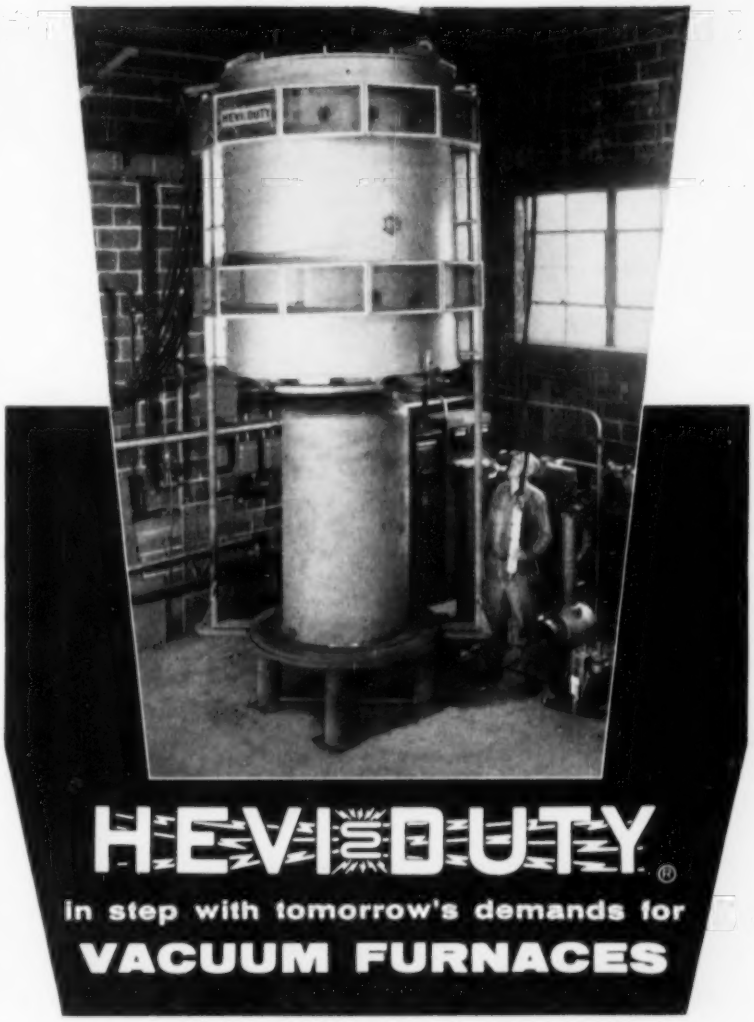
grant to the National Bureau of Economic Research by the National Science Foundation. In numerous areas the information necessary to reach precise conclusions is incomplete, and their report provides a valuable guide to types of economic information needed for fuller and deeper understanding of the technological professions.

Compilation of Steel Piping Materials, *American Society for Testing Materials,* 1916 Race St., Philadelphia 3, Pa., 455 pp., $4.50, 1957.—The great need for materials to handle hot liquids under pressure makes this compilation a timely addition to the libraries of chemical and mechanical engineers, petroleum engineers, utility facility designers, and those concerned with nuclear power. Among the topics covered are pipes; boiler, superheater, and miscellaneous tubes; steel tubes; heat exchanger and condenser tubes. The volume contains 60 specifications, one method of test, and one classification. •

Brittle Behavior of Engineering Structures, by Earl R. Parker, *John Wiley & Sons Inc.,* 323 pp., $6.00, 1957.—This book summarizes the available information on the brittle behavior of steel in engineering structures. It contains a discussion of the theories and mechanism of failure, a review of test methods used for evaluating relative brittleness, interpretations and summaries of test results, a discussion of the effects of welding composition variations on notch toughness, and a report of service failures. •

Elements of Partial Differential Equations, by Ian N. Sneddon, *McGraw-Hill Book Co. Inc.,* 327 pp., $7.50, 1957.—The book covers the elements of the theory of partial differential equations in a form suitable for the use of students and research workers whose main interest in the subject lies in finding solutions of particular equations rather than in the general theory. Many worked examples and practical problems for solution by the reader are included. •

The Machining and Grinding of Gray and Nodular (Ductile) Cast Irons, by Norman Zlatin and Charles F. Walton, *Gray Iron Founders' Society Inc.,* 930 National City—E. 6th Building, Cleveland, Ohio, 57 pp., $3.00, 1957.—The Manual is intended for use in the design, engineering, and production of cast components. Abundantly illustrated and including numerous commercial and practical examples, it constitutes a real down-to-earth and ready reference on machining, abrasive finishing. •



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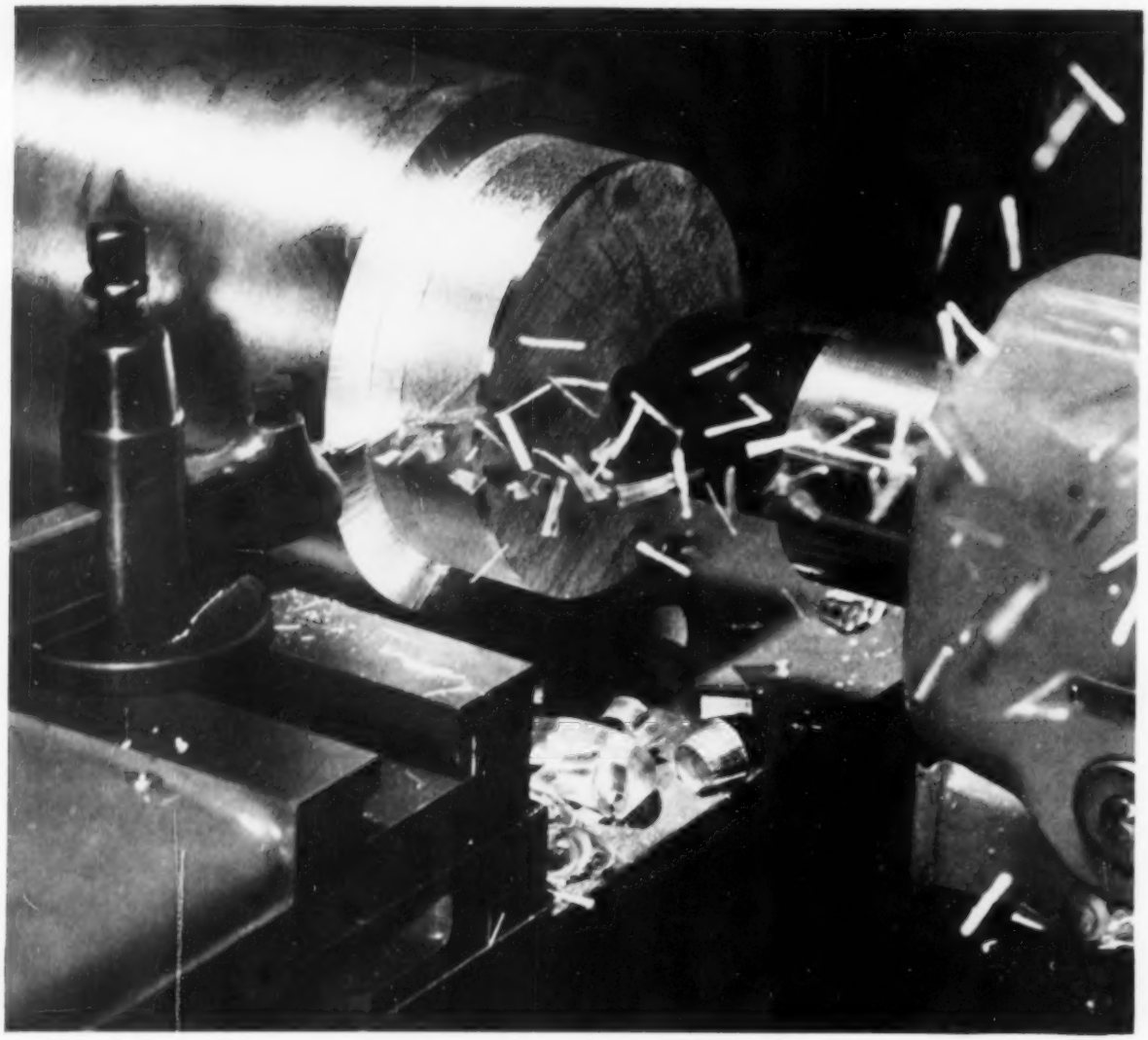

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EDITORIAL

Responsibility

by Herbert Hoover, Jr.

Acceptance speech by Mr. Hoover following presentation of the Hoover Medal (joint award sponsored by the Four Founder Engineering Societies: AIME, ASCE, ASME, AIEE) at the annual banquet held during the AIME Annual Meeting in New Orleans on Wednesday, Feb. 27, 1957.

IT is one of the greatest honors that can come to any engineer to accept this award from the Four Founding Societies. For me, in this instance, it is doubly so.

First, there are few honors that can come to a professional man for which he is more deeply grateful than one that comes from his own fellows in the profession. And, secondly, added to this gratitude on my part is the appreciation that this award was named in honor of my father.

It has been the purpose of this award to recognize public service among engineers. To that principle I most heartily subscribe, for engineers have a particular opportunity and responsibility to tackle many of our present day problems. That they are doing so in increasing numbers is a logical outgrowth of their training, their experience, and of the traditions of their profession.

Many of the complexities that we face today, whether they are of community, national, or international character, have their origins in the very same situations that engineers are dealing with on a day to day basis.

As civilization moves forward, the demand for tangible things becomes ever more insatiable. The worldwide desire for a better standard of living, in the physical sense, is increasingly an engineering job—the job of translating our expanding knowledge of science into practicable goods and services. This technical area has, by popular conception, always been among the primary provinces of the engineer. What is not so generally realized, by the public at large, is that the engineer is usually just as much at home in dealing with an extraordinary variety of nontechnical problems.

Today, no engineer can do his job, particularly if he has management responsibilities, unless he is thoroughly conscious of the social, political, and economic factors that are at work around him. He takes them into account and deals with them just as seriously as he does with the physical problems of molecules, mathematics, or machinery. And he must be on equally as firm ground with respect to both theory and practice in working with these intangible forces as he is when handling the more tangible ones.

In fact, whether at home or abroad, many engineers gain a wider background of direct experience in dealing with governmental and social problems than is, perhaps, afforded to any other group.

Their work, whether in a professional or managerial capacity, brings them into frequent relations with many executive agencies and legislative bodies. In the process, they have explored the workings of much governmental machinery.

They have come to know at first hand something of the aspirations and ideals of people, as well as of the conditions and the productivity of their employment.

Most engineers have learned, too, that the laws of economics and finance are just as inexorable as the laws of nature and that theirs cannot be a world of wandering decimal places!

Out of these, and a myriad of other experiences, they have developed a thoroughly realistic and practical approach to idealism.

There are probably other reasons, besides training and experience, why engineers find themselves in public service. One of them, perhaps above all others, is the sense of responsibility that stems from the traditions of their profession.

As we look into the future, certainly, engineers will be faced with more responsibilities than ever before, both inside and outside their profession. The younger men, in particular, who are just beginning their careers, have an ever widening range of opportunities. To them, I would urge that they gain the broadest possible grounding in the fundamentals of the physical sciences and engineering and that they do the same in the social sciences and economics. On the technical side, the problems of tomorrow will not be confined to any one narrow area, for all of the fields of science and engineering are becoming constantly more interrelated.

Later, as these young men move forward in their profession, and especially if they assume management responsibility, they will find that the human, civic, and economic problems will become fully as important as the technical ones. It is here that a breadth of knowledge and a thorough grounding in fundamentals is as important as it is to have a sound technical foundation.

To these younger men, let me say one further brief word. They are entering one of the most constructive and honorable of the professions. They will have the satisfaction of working in a field which has almost limitless opportunities to contribute toward the betterment of mankind.

They are also entering a profession which, for generations, has demanded those high standards of honesty and integrity that we are proud to recognize among the foundations of our American way of life; for our engineering heritage places frank emphasis on moral and spiritual values and upon dedication to public service.

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This technique provides data which is otherwise unattainable. In addition, it provides an indispensable complement to microscopic techniques – not only where distortion must be verified, but also to reveal the superimposed details of opaque materials with ultra-sharp focus throughout the entire thickness of the sample. Because of the straight-line penetration characteristics of X-rays, critical studies of internal structures of semi-transparent and transparent structures may be routinely made. In practice, the specimen is placed in contact with a fine-grain film. Vacuum camera may also be employed. An ultra-thin window X-ray tube provides select long wave radiation penetration. (1-1) micrographs can be enlarged 400-500x photographically.

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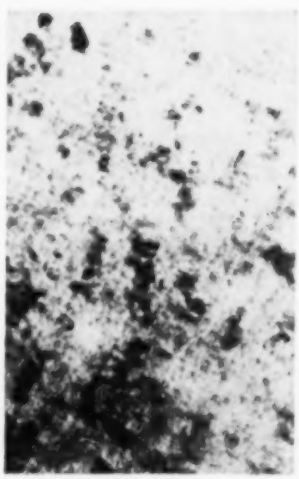

90% Cu - 2% Be - 20 micron section 5 Kv - 3 Ma - exposure time 4 mins. Enlargement 135 X.

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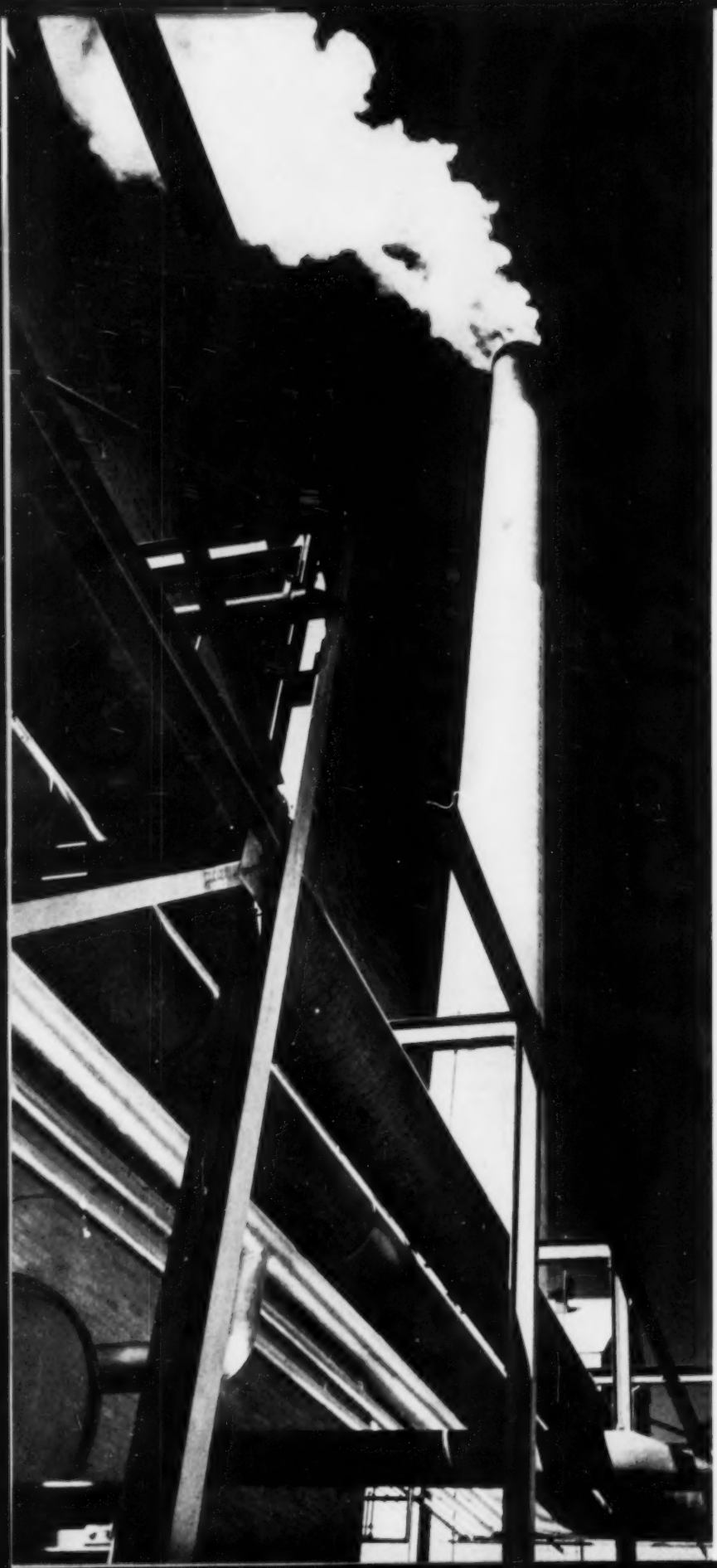

NONFERROUS OPERATIONS

The San Manuel Smelter

The Gaspe Smelter

by G. C. McKerrow

GASPE Copper Mines Ltd. is situated at Murdochville, Que., in the Gaspe Peninsula, about 460 miles northeast of Montreal. Sixty miles from the Port of Gaspe and 30 miles from Port of Mont Louis, highways connect with Murdochville which is not served by a railway.

The smelter was designed to treat 450 tpd of concentrates and produce 110 tons of copper. Construction started in 1953 with completion scheduled for early 1955. However, the whole project suffered a postponement due to a year's delay in receiving hydroelectric power. Fires were lit in the reverberatory furnace on Nov. 13, 1955 and smelting of concentrates began on December 2nd. The first anodes were cast on December 9.

Low grade copper ore is used for flux and is crushed and transported as far as the concentrator by the same conveyer system that supplies the concentrator with ore. Flux and concentrates are sent to the smelter from the concentrator on separate, superimposed conveyers which are housed in a common gallery. The concentrate storage pond adjacent to the mill was built to take care of concentrate production before the smelter started, and for subsequent surges in production or interruptions in smelting. The pond is a concrete-lined basin into which thickened concentrates can be pumped. They are reclaimed by washing into a sump from which they are pumped to the thickener to join current production. Capacity of the pond is between 12,000 and 14,000 tons.

Receiving department

Concentrates are received by conveyer from the concentrator and are stored in two 250-ton bins.

The concentrates are drawn from these bins at the rate of 150 tons per hr and pass over a conveying scale followed by an automatic sampler. Moisture samples are cut manually at the discharge of the scale. A series of conveyers carry the concentrates to two bins above the firing end of the reverberatory furnace. It requires about 3 hr on day shift to deliver a day's supply of concentrates to the reverberatory bins.

The receiving department has two 200-ton bins for storing siliceous ore conveyed from the underground crushing plant. The flux as received is about 25 pct +1 in. From the storage bins it is passed over a double deck vibrating screen where the +1 in. material is sent back through a 3 ft cone crusher in closed circuit with the screen. Usually the −1 in. material is sent to the converter flux bins or to the fettling bins at the furnace. However, if the flux is too wet or contains too many fines, the −¼ in. fraction can be removed by using the lower deck of the screen.

For handling reverts, or fluxes in case of an interruption in the regular supply, there is a 50-ton bin ahead of a 15x30-in. jaw crusher. The products of this crusher go to the 3-ft cone crusher and then join the flux screening and handling system. The −¼ in. product from the screen can be stored in either of two 50-ton bins. These bins have feed gates and belts with variable speed drives which allow the materials to be sent to the smelter bins at a rate of 50 tons per hr, or they can be so regulated that small additions of the order of 1 or 2 pct can be made to the concentrates as they are being sent to the smelter.

A 15-ton capacity surge bin mounted over a pug mill receives flue dusts. After the dusts are pugged with water they are normally discharged on the conveyer carrying concentrates to the reverberatory furnace bins.

Reverberatory furnace

The reverberatory furnace measures 105x30 ft from face to face of the binding steel, and 99x25½ ft inside the brick work at the normal slag line. The furnace foundation consists of a band of reinforced concrete extending to bed rock. The foundation, including two transverse ribs tying in the sides, was poured as a single block, except the firing end wall which was poured separately. Above the foundation for the first 5 ft, instead of brick walls, beams

G. C. McKERROW is Smelter Supt., Gaspe Copper Mines Ltd., Murdochville, Que., Canada. Paper presented at the AIME Annual Meeting, New Orleans, February 1957.

were cast of reinforced concrete made from aluminous cement and Haydite aggregate. At the firing and skimming ends of the furnace these beams were anchored by steel rods to concrete *deadmen*.

Brickwork walls are made of composite silica and burned chrome-magnesite brick. Copper water jackets are used in the firing wall and at the slag line in the skimming area where the walls cannot be protected by fettling. The roof of the furnace and the outlet flues are of suspended basic brick. The suspended roof and the charge floor with its feeding equipment are supported by the buckstays.

The original plans for the bottom called for a foot of rock fill, 5 ft of tamped Noranda reverberatory slag and 3 ft of fused magnetite concentrates. When it appeared likely that frozen magnetite would have to be handled in the winter, it was decided to substitute a mixture of 75 pct roll scale and 25 pct reverberatory slag for the magnetite concentrates. After tamping 30 in. of this mixture in place the furnace was fired with the intention of adding more as the fused material slumped. When a pool 1 ft deep and 45 ft long had formed, molten slag penetrated down one side of the furnace until it reached the aluminous cement concrete. It cut through this material and welled up on the outside of the brick wall, burning two buckstays.

After a two-day delay for repairs, siliceous flux was charged along the side walls to protect them, and straight roll scale was blown into the middle of the furnace and melted down. A refractory bottom was secured for the firing-end zone in this way but the fettling was attacked and slag containing 15 to 20 pct silica flowed into the skim end where it covered but did not penetrate the tamped bottom material. When the level of the molten slag reached the matte tapholes, fusion of roll scale was stopped. The bottom was allowed to anneal for four days at 2100°F. and then charging the furnace with concentrates was begun. After smelting for three weeks, matte penetrated the fused slag layer in the skimming end of the furnace and rapidly replaced the underlying roll scale and slag mixture. In two weeks the matte had penetrated to an average of 2 ft below the taphole level over an area approximately 15x40 ft. The replacement which occurred at irregular intervals over areas of 20 to 40 sq ft was accompanied by a violent boiling, probably due to the escape of moisture. The original fused bottom in the first 45 ft was not affected and has shown little erosion to date.

The furnace is side charged by flight conveyers which are 94½ ft long with charge pipes spaced at 3-ft intervals along each side. Concentrates are charged for a distance of 70 ft from the firing wall; the remaining 25 ft of wall served by the conveyer is fettled with siliceous flux.

Two 50-ton bins are located between the concentrate storage bins above the firing end of the furnace. Below these bins is an 18-in. reversible shuttle belt which can feed either the flight conveyers or the charge bins for fettling the firing wall. The bins discharge on a small vibrating feeder which allows measured amounts of flux, or revert material if this is available, to be fed at one to four tons per hr together with concentrates. One bin has a second discharge pipe which feeds fettling flux at about 20 tons per hr. The purpose of these bins is to allow corrections to be made to the furnace charge and provide fettling material for the firing wall and side walls.

Although it had been planned to haul slag to the dump in a Diesel-electric locomotive, it was realized that heavy snowfalls would present serious difficulties. It was decided that Diesel trucks could handle molten slag and one with a 120-cu ft pot was ordered. It has been in successful operation since August 1955.

The firing system of the reverberatory furnace originally consisted of four mechanical atomizing burners and two forced draft fans. The primary fan is rated at 13,000 cfm at 14 in. of water pressure and is driven by a 50-hp motor. The secondary fan, rated at 13,000 cfm at 6 in. of water, is driven by a 20-hp motor.

If the skimming end of the furnace is cold, auxiliary burners in the sidewalls, about 20 ft from the skimming-end wall, are used rather than lengthening the flame from the main burners. At the relatively low firing rates which have been required to date, it was found desirable to use only the two inside burners. The other two burners have been removed and the ports bricked up. These two burners have performed satisfactorily with firing rates up to 600 gal per hr.

By measuring and regulating the supply of fuel and air and controlling the furnace draft, good fuel economy is achieved. The fire is very steady and analysis of the furnace gases with an Orsat apparatus is made only twice a shift. Gases at the sampling point 75 ft from the firing wall run 0.4 to 0.8 pct O_2 and no CO.

Converters

The converter aisle is 200 ft long; the crane rails are 49 ft above the ground with a 60 ft span between the rails. There is a 50 ft span between the columns supporting the crane rail girder in front of the reverberatory furnace, which will allow the furnace to expand towards the converter aisle without interfering with the crane runway.

There are two 13x30 ft Peirce-Smith converters of conventional design except the riding rings are 18 in. wide instead of the usual 15 in. The 50 tuyeres are spaced at 6-in. centers with 1⅞-in. tuyere pipes. Tuyeres are punched manually. The converters have single Garr guns supplied by 18-in. conveyer belts running from 150-ton flux bins, which are in a separate building bay behind the converter flue.

Weighing feeders provide the weight of flux used per *blow* and also per shift or day. Behind the puncher's platform there is an indicating flow meter for the air supplied to the converter and an indicating and recording radiation pyrometer, sighted through the hood into the converter mouth. In the converter office there are running time meters and

Diesel truck with 120 cu ft pot used to haul slag to the dump.

a recording and integrating flow meter for air delivered to the converter.

Air is supplied by a turboblower rated at 25,000 cfm at 16 psig and driven by a 1900-hp synchronous motor. In case of power failure to the blower, the converter is turned over automatically by a storage battery set.

Anode furnace

The Anode furnace follows Noranda design with a monolithic bottom of fused magnesite clinker and roll scale, and a suspended basic roof and uptake. Maximum capacity of the furnace is 145 tons. Bunker C oil is used as fuel with a steam atomizing burner. Copper is poured by a hydraulically operated spoon into molds on a circular casting wheel carrying 20 molds. The wheel has a Ward-Leonard drive for smooth acceleration and deceleration, and the molds are automatically positioned beneath the spoon. 625-lb anodes are cast at the rate of 40 tons per hr. The anodes are cooled by water sprays and lifted by a compressed air hoist into a bosh tank for further cooling before being stacked for shipment to the refinery.

Waste heat boilers

There are two waste heat boilers, each with 1260 sq ft of heating surface in the furnace section and 9224 sq ft in the boiler section. The design called for each boiler to make 25,000 lb of steam per hr at 450 psig and 650°F under normal operating conditions, and to be able to produce 50 pct more steam without an unduly high rise in the outlet gas temperatures in case the other boiler was shut down.

The flue from the reverberatory furnace branches into two arms and the boilers are placed in line with their respective inlet flues. This layout avoids changing the direction of the gases at the point of entering the boiler, which could result in concentrating the dust load on one side of the boiler, and promoting either accretions, tube erosion, or both.

Water-cooled dampers at the inlets allow either boiler to be isolated for inspection or repairs. In each boiler there are ten soot blowers in the water wall section and ten in the convection section. Soot blowing is done once a day using air at 250 psi. Very little hand lancing is required.

Power is generated from steam not required for plant heating in a single 5400 kw turbogenerator. To avoid interruptions to smelting in case the turbogenerator has to shut down, extra blow-off valves were provided on the boilers in addition to the regular safety valves, and the water treatment plant was made large enough to supply the boilers at the normal operating rate without the turbine condensate returns.

Flues and cottrell

The smelter layout results in a long converter flue but allows converter and reverberatory gases to mix before entering the cottrell, and leaves one side of the smelter open for future expansion.

Where the flues run outside the smelter building they are protected from the weather by asbestos board housing.

Flue dust is removed by pipes with shutoff gates which discharge into drag conveyers, except between the two converters where it is discharged directly into buggies. The coarse dust caught in buggies, together with the dust collected in the first 80 ft of flue beyond the converters, is charged to the converters. The dust from the remainder of the flues ahead of the cottrell is discharged into a surge bin beneath the cottrell dust hoppers and pumped to the receiving department.

The cottrell electrical precipitator consists of three units in parallel, each unit having three sections in series. Each section has 22 rod-type curtains for low tension electrodes. Rapping both the high and low tension systems is done pneumatically with automatic and manual controls. Total power input varies between 70 and 80 kw.

The collected dust is drawn from hoppers beneath the precipitators by screw conveyers and is discharged into the same tank as the flue dust, from which it is pumped to the receiving department.

The stack is 500 ft high, 32 ft ID at the base and 18 ft ID at the top. Between the concrete shell and the acid-proof brick lining there is 2 in. of fiberglass insulation.

Operations

Gaspe concentrate contains 80 to 85 pct chalcopyrite with minor amounts of bornite, pyrrhotite, and lead and zinc sulfides. The gangue in the Gaspe Copper orebodies is a silicified limestone and both the concentrates and siliceous fluxes contain appreciable amounts of lime. This lime content is sufficient to give reverberatory slags running 5 to 10 pct CaO. If the converter slags are kept high in silica, little or no siliceous flux, except for fettling, need be added to the furnace charge. The converter flux containing 68 to 75 pct SiO_2 and 8 to 13 pct lime, with low iron and alumina, is chemically almost ideal. The concentrates assay 0.025 pct Bi, the effect of which will be noted later.

Smelting practice is conventional with the most notable points being low slag losses and low fuel ratios. For 24-hr periods, slags have been as low as 0.19 pct Cu with a 33 pct Cu matte. Slag losses are lowest when the silica is over 37 pct and lime over 7 pct. In addition, the slag as tapped should be relatively cold, that is, in the 1980° to 2030°F range. With a short oil flame and readily fusible charge, low temperature slags can be run until the tonnage rises above 450 tpd. Then, the higher smelting rate increases the slag temperatures to above 2100°F and losses will increase by 0.03 to 0.05 pct Cu.

Low fuel ratios are due in part to the nature of the nonsulfide portion of the concentrates which has a silica to lime ratio of 2.5 to 1 with low alumina.

The addition of 5 to 10 pct flux to the charge raises the fuel consumption per ton by 15 to 20 pct.

The difference in elevation between the bottom of the slag skimming slot and the matte taphole is 36 in. Above the level of the matte taphole, 50 in. of liquid are carried with 15 to 25 in. matte. Possibly owing to the depth of the slag in the furnace, there have been no explosions due to wet concentrate coming into contact with molten matte.

The outlet flue from the furnace originally had an area of 90 sq ft. This was too large for firing rates of 300 to 500 gal per hr. The area was reduced to 51 sq ft; but this reduction was not enough to keep the boilers from smoking. Negative pressure on the boilers was finally achieved by building walls 4 ft high in the flues at the entrances of the boilers, and lowering the water-cooled dampers,

until the combined open area of the flues at this point was reduced to 40 sq ft.

One converter can produce 135 tons of copper per day from 33 pct matte. At the present production rate the converter is operating a little more than half the time.

The converter temperature is kept around 2100°F while making flux additions and slags are skimmed at 2240°F. With a single converter operating, it saves a great deal of time to finish copper with a granulated slag, and thus avoid having to skim slag, pour it into beds, and charge it to the converter again when it is cold. The radiation pyrometer has been useful in enabling the operators to consistently finish with granulated slags.

Molten blister copper is poured into the anode furnace, and refined and cast in the usual way. Minimum charge is 90 tons, and 145 tons is the maximum that can be cast. At present 18 to 20-anode charges are made in a month. About 650 gal of oil per day are required to keep the furnace at operating temperatures and fuel consumption is approximately the same whether copper is cast or the furnace is idle. Casting temperatures are maintained between 2060 and 2090°F.

The molds, which weigh approximately 5200 lb each, are of wire bar copper cast by the Montreal East refinery.

The original plans called for a reverberatory tonnage of 500 tpd composed of 450 tons of 24 pct copper concentrates and 50 tons of siliceous flux. It was estimated that as high as 5.5 million Btu's might be required per ton of solid charge and that half the heat would be recovered as waste heat steam. Waste heat steam production would then be about 45,000 lb per hr, nearly all of which would be available for power generation in the summer. This would require a 4500-kw generator. A 5400-kw generator was chosen to provide extra capacity.

The normal furnace tonnage is now 400 tons per day due to higher grade concentrates and the small amount of flux required. This tonnage and the low fuel ratio have resulted in a steam production rate of 25,000 to 30,000 lb per hr and consequently the turbogenerator is too large. During periods of low tonnage, or when the heating steam demand is high, the boilers have to be direct fired to keep the turbogenerator output above 1000 kw. Below this figure turbine speed regulation is poor.

The cottrell plant performance has been very good. Gas temperatures and volumes vary considerably, depending on whether the converter is blowing or not. Maximum temperatures have been in the neighborhood of 650°F, and maximum volumes around 250,000 cfm at flue conditions. The draft at the base of the stack averages about 2.5 in. of water. The draft controller on the stack damper is normally set to give 0.8 to 1.0 in. of draft at the Cottrell outlet.

The converter flue requires about 0.3 in. of draft to keep the hood from smoking. The draft controller on the converter flue damper cannot cope with the fluctuations of gas flow when the converter is turned into or out of the blowing position, unless there is a good margin of draft on the stack side. During periods when the converter is not operating the cottrell outlet draft can be reduced to 0.4 in.

The cottrell dust collected has varied from 45 to 70 tons a month containing 18 to 22 pct Cu. 95 to 97 pct of the copper entering the cottrell is recovered.

The one serious metallurgical problem at Gaspe has been bismuth. The concentrates contain variable amounts of bismuth averaging about 0.025 pct. Approximately 80 pct of the bismuth input is caught in the cottrell. During the first weeks of smelter operations the cottrell dust was charged into the reverberatory furnace with the concentrates. The circulating load of bismuth soon built up to a level where the cottrell dust contained 16 to 18 pct and the anode copper contained 0.1 pct Bi. Charging cottrell dust to the furnace was discontinued and the dust has since been stockpiled while a plant is being built to remove the bismuth from the dust. Since the concentration of bismuth in the other flue dusts is much lower, normally only cottrell dust is stockpiled. With the cottrell dust withdrawn from the circuit, the anode copper contains 0.004 pct Bi, which is 4 pct of the input. Approximately 16 pct of the input escapes up the stack.

Operating Statistics for the Gaspe Smelter

Typical analyses of smelter feed and products

	Au, Opt.	Ag, Opt.	Cu, Pct	SiO_2, Pct	Fe, Pct	S, Pct	CaO, Pct	MgO, Pct	Al_2O_3, Pct	Bi, Pct
Concentrates	0.025	4.0	28	7	28	29	2.0	0.5	1.2	0.03
Fluxing ores		0.2	0.6	72	4	1	10.0	2.0	2.5	
Reverb matte	0.03	5.0	33		35	28				0.03
Reverb slag		0.02	0.27	39	34	0.8	7.0	1.6	3.2	nil
Converter slag		0.6	1.6	31	44	0.9	4.0	0.8	1.5	nil
Reverb flue dust		3.0	22	8	21	8	1.8			0.5
Converter flue dust		5.0	46	15	11	13	2.5			0.22
Cottrell dust		5.0	21	11	9	10	2.2			5.0
Anode copper	0.13	14.0	99.6							0.004

Reverberatory furnace	April 1956	October 1956
Concentrates smelted, tons	9,680	8,293
Siliceous flux smelted, tons	340	233
Flue dust smelted, tons	28	40
Total solid charge, tons	10,048	8,566
Furnace days	30.9	26.25
Solid charge per furnace day, tons	325	326
Oil per ton solid charge, gal*	25.9	26.7
B.t.u.'s per ton solid charge	4,690,000	4,800,000
Converters		
Siliceous ores smelted, tons	3,183	2,908
Matte treated, tons	8,280	7,200
Converter slag produced, tons	7,150	6,000
Blowing time, hrs	318	269
Average vol. air, cfm	22,700	23,900

Anode furnace	April 1956	October 1956
Anodes produced, tons	2,580	2,169
Oil burned, gal*	26,681	20,427
Anodes per charge, tons	108	114
Anodes cast per hr, tons	42.7	41.8
Total ores and concentrates smelted	13,293	11,434
Copper losses as pct of input		
Slag	0.82	0.94
Stack and handling (estimated)	0.35	0.35

* Gallons in this article are Imperial gallons = 1.20 U. S. gal.

The El Paso Smelter

ASARCO's El Paso works has, since 1887, grown with the Southwest mining industry.

by T. J. Woodside and B. Roberts

EL PASO Smelting Works, founded in 1887, is one of the oldest nonferrous smelters in the U. S. Its history reveals much of the usual vicissitudes of custom smelter operations, and also contains a few unusual factors which have contributed to the development of the present plant.

The early 1880's saw much activity in lead mining in Mexico. The Sierra Mojada and Santa Eulalia mining districts of Chihuahua were stimulated to greater production by the activity of buyers who were shipping ores to Colorado and elsewhere for smelting. One of these ore buyers was Robert S. Towne, who built a railroad to the north, from Chihuahua City to El Paso. He first established a sampling plant at El Paso, and in 1887 built a small lead smelter with a capacity of 150 tons of ore daily, on the site of the present plant. A few months after completion, it was taken over by the Consolidated Kansas City Smelting and Refining Co., with which company Towne was associated and he became the first general manager. In 1899 the American Smelting and Refining Co. was organized, and the Consolidated Kansas City Smelting and Refining Co. was absorbed in this organization. El Paso Smelting Works has remained a unit of ASARCO to the present. In the early 1900's, copper production in the southwest assumed substantial proportions, and

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ASARCO constructed copper blast furnaces and a converter at the El Paso plant, followed in 1912 by reverberatory furnaces. The slag fuming plant for zinc recovery was constructed in 1948.

El Paso has always operated as a custom smelter and, beginning with the ores from Sierra Mojada in Chihuahua, its principal sources of lead ores and concentrates have been New Mexico, Arizona, and, at present, Africa and South America. The copper smelter started with the smelting of oxide ores from Arizona and New Mexico, followed by sulfide concentrates in 1912 from Chino Copper Co. at Santa Rita, New Mexico, and later many producers in Arizona and the southwest. Today the principal source of copper concentrates is ASARCO's Silver Bell mine northwest of Tucson, Ariz.

The plant proper occupies about 65 acres located two miles north of El Paso. Delivery of all materials moving by rail is made by the Panhandle and Santa Fe Railroad, but the city is served by many railroads. This location, at a railroad center, has been a big factor in the long effective operation and growth of the smelter. Another factor has been the gradual enlargement of the southwestern mining community, bringing about a corresponding enlargement of smelting facilities, so that today the plant is versatile and can bid competitively for ores and concentrates throughout the world, even though situated about 600 miles from the nearest seaport.

Ore handling

Except for a few truck lots, ore is received in railroad cars. Cars are weighed loaded, again when empty, and moisture samples, consisting of two kilos taken from at least two post holes, are taken and dried at 220°F for 48 hr. Concentrates and other fine materials are pipe-sampled in the car; granular materials, such as retort zinc residue, are augur sampled, and crude ore and other coarse materials are put through the crushing plant where an automatic sample is cut. Due to the very great variety of ores and byproducts received, a grab sample is taken immediately after weighing all lots where the metal or impurity content is not definitely known, as a guide to disposition.

The crushing plant consists of a 300-ton bin feeding a No. 8 Gyratory followed by a 4 ft Symons cone. The Symons product, most of which is —1 in., goes to a Vezin sampler which takes a 1/5 cut. The sample passes through 30x14-in. rolls followed by another Vezin taking a 1/10 cut, a second set of rolls, and finally a duplex Vezin cutter taking the final sample for the bucking room. Reject from the sample train goes to 54x24-in. rolls in closed circuit with a 4x8-ft Tyler screen. The final product, —⅜ in., goes to the ore bins or to railroad cars for stockpiling. The rolls and screen are bypassed when crushing converter flux.

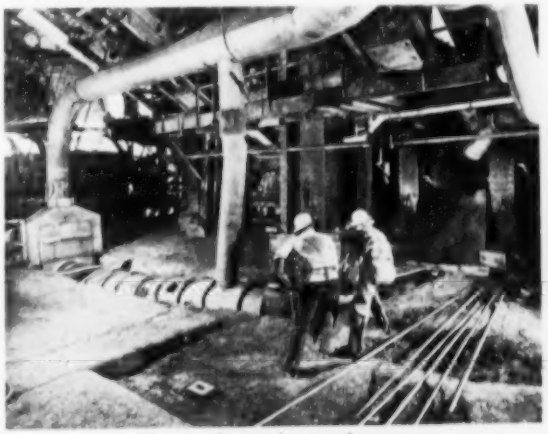
Box cars containing concentrates are unloaded to belt conveyors by pay-loader or by hand shoveling. Dump cars containing material not requiring crushing are dumped directly into ore bins. Copper concentrate in open cars is unloaded by crane to a tripper belt feeding the bedding bins.

Ore bins are housed in a single building divided down the center, one side being used for copper and the other for lead. The copper side contains three bedding bins of 1700 tons capacity each, used for wedge roaster charge, and five 200-ton pocket bins for converter flux and other direct smelting materials. The lead side contains five 600-ton bedding bins, used for concentrate, and nine pocket bins.

Lead smelting

Dwight-Lloyd charge is made up by proportioning pan feeders discharging onto a longitudinal belt beneath the bins. The charge is screened through ½-in., the oversize going through 24x30-in. corrugated rolls, and conveyed to a 11-ft diam mixing table at the top of the sinter plant, where return fines from the first-over machines are added. From the mixing table the charge is distributed by tripper belt to hoppers over each of the first-over machines. A variable speed mixing table under each hopper serves to control feed to the machines.

Three 42 in. by 22-ft and one 63 in. by 31-ft machines are used on first-over. Pallets discharge onto a pan conveyor feeding 34x20-in. corrugated rolls followed by 54x24-in. smooth rolls. The product, crushed to —½ in., is raised to the charge floor level by bucket elevator and conveyed to final machine hoppers, the charge mixing table or to a 100-ton storage tank.



Tapping the reverberatory furnace.

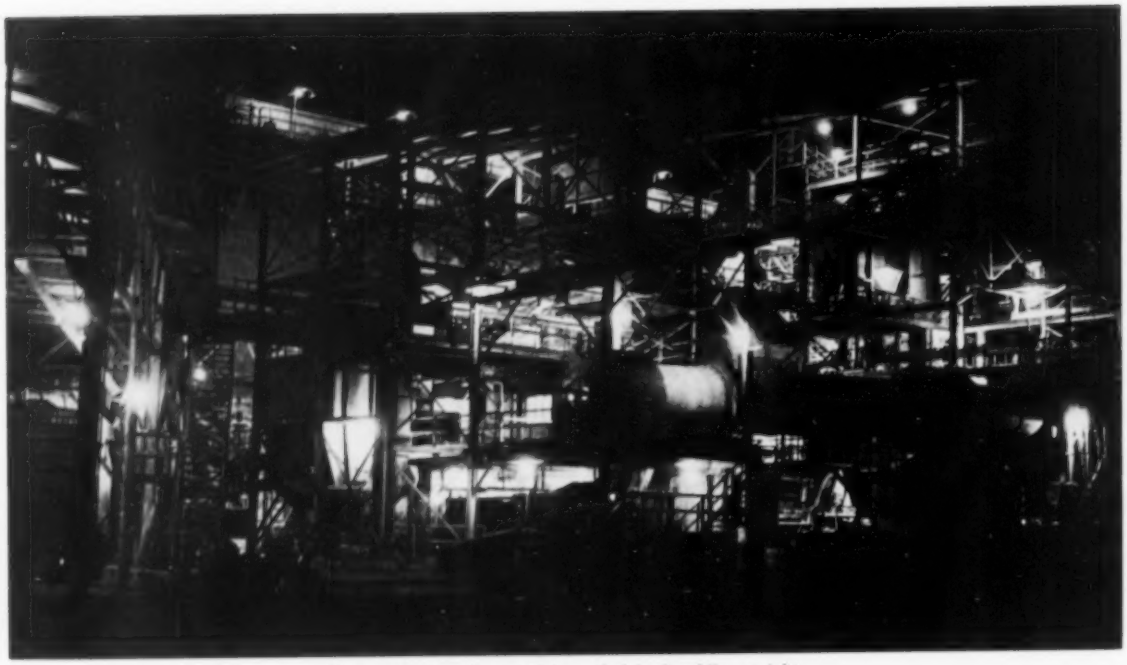
To the raw charge, which carries 10.5 to 11 pct S, is added sufficient return first-over sinter averaging 4.5 pct S to bring sulfur in the feed to 8 pct. One 63 in. by 31 ft and one 63 in. by 40 ft machine produce final sinter averaging 1.5 pct S, 25.5 pct Pb, and 7.3 pct Cu.

The larger machine has water-sealed wind boxes and is equipped for recirculation of gas from the final wind box. Charge consists of crushed first-over sinter plus 2.5 pct coke breeze or low volatile coal. Cast stainless steel grate bars are used on all machines. Ignition muffles are fired by natural gas.

Gases from all machines are cooled to 220°F by water sprays in a concrete chamber ahead of a ten-section baghouse containing 1760 18 in. by 30-ft wool-dynel bags. An unlined concrete stack, 610 ft high, serves the baghouse.

Sinter is drawn from discharge hoppers of the final machines into three yard double side dump storage battery trucks which transport it to the furnace charge cars. Coke is added to the charge cars from weigh-hoppers, and any direct smelting material is dumped in by a front-end loader. Charge cars are raised to the feed floor by hydraulic elevators.

There are three 56 in. by 15-ft thimble top blast furnaces. Effective height of column is 22½ ft from tuyeres to bottom of thimble. Two furnaces are in continuous operation with the third in reserve. No



The slag fuming plant at night, with delcading kilns at right.

lead well is used, all molten furnace products being tapped into a rectangular, brick lined, steel settler mounted on trucks. Due to the very high temperature of the metal, no separation of matte and speiss from the lead takes place in the settler so that it is all tapped together into 15-ton brick lined pots for transfer by rail to the drossing plant. Slag flows from the top of the settler into a second settler which is unlined and thence to 12-ton ladles mounted on transfer cars, for transport to the fuming furnace.

Furnace lead carrying nearly 50 pct dross-forming materials is poured into one of three 65-ton cast iron kettles. The lead is still at a temperature of 1800°F when it reaches the kettles, consequently kettle life is very short, three months being exceptionally good. Soda ash, coke breeze, and Dwight-Lloyd baghouse dust are added as the kettles are being filled and the dross is removed before it becomes too solid with a ¾-yard clamshell bucket operated by a 10-ton monorail crane, and charged directly to the dross reverberatory. After rough drossing, the lead is baled out by the crane, using a cast steel bucket holding 5 tons, and poured into a 130-ton cast iron kettle where a second drossing is done. Final drossing and decopperizing with sulfur is done in a second 130-ton kettle. Bullion is cast into 10-ton pigs for shipment to the Omaha and Perth Amboy refineries.

Dross is smelted in a 28x8-ft gas fired, water-jacketed reverberatory furnace. Products of the furnace are soda matte, speiss, and lead bullion. Matte is transferred molten to the copper converters. Speiss, because of its arsenic content, is granulated and shipped to San Luis Potosi. Lead is tapped directly into the drossing kettles.

Blast furnace and reverberatory furnace gases are mixed, cooled by water sprays to 160°F and passed through a 12-chamber baghouse containing 960 18 in. by 30-ft woolen bags.

All dust from the blast furnace baghouse is roasted for cadmium concentration in a 26-ft Godfrey roaster. The roaster charge is made up of 65 pct dust, 20 pct crushed limerock, and 15 pct coal. The fume, 60 pct Cd, is recovered in a 135-bag baghouse and shipped to the Globe Plant in Denver. Residue is returned to the sinter plant.

Copper smelting

Four seven-hearth 22½-ft ID, gas fired, Wedge roasters are available for roasting reverb charge. Normally three are used, each producing 275 tons of calcine per day with 7.5 units sulfur elimination. Calcine is hauled in 5-ton larry cars.

The reverberatory furnace is 117 ft long by 26½ ft wide. The crucible is water-jacketed from bridgewall to skimbay with cast copper jackets. Deep bath smelting is practiced, with charging being done through four Wagstaff guns. Burner air is preheated to 400°F by steam-condensing air heaters. The sprung silica arch is sufficiently maintained by slurrying to achieve campaigns of two years. Two Erie City waste heat boilers produce steam at 400 lb and 700°F. Reverb fuel ratio averages 3340 thousand Btu per solid ton.

Reverb and roaster gases are mixed and pass through a four-section plate and wire cottrell; dust recovery averages 96.5 pct.

Converting is done in three 13x30-ft Pierce-Smith converters, of which two are normally in operation. Magnetite coating is used. An average of 22,000 tons of blister is produced between tuyere relinings. Converter flux carries from 70 to 80 pct SiO_2 and to it is added 20 pct retort zinc residue. Blister production averages 107 tons per converter day. Air is supplied by a fully automatic 30,000 cfm turboblower, with two blowing engines in reserve.

A steel balloon flue carries converter gas to a brick spray chamber where it is conditioned with water and sulfuric acid before entering a seven-unit plate cottrell which recovers 93 pct of the fume. After the cottrell gases are combined with those from roasters and reverberatory, they pass out through a 400-ft brick stack.

Blister copper is fire-refined in one of two 160-ton tilting anode furnaces and cast into 690-lb anodes for Perth Amboy on a 22 mold wheel.

Slag fuming

The slag fuming furnace is located at the end of the converter aisle. A water-jacketed flue connects it with a Stirling-type waste heat boiler rated at 72,000 lb of steam per hr. Two fans in parallel at the economizer exit force the dust-laden gases through two banks of U-tube coolers, each bank having forty 30 in. by 58-ft tubes. Two more fans are located between the U-tubes and the baghouse.

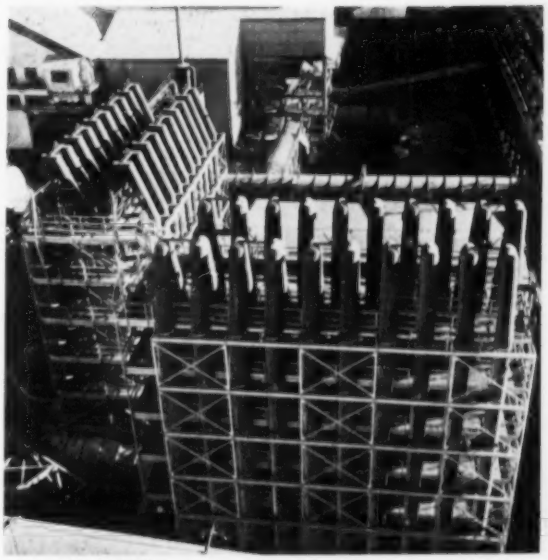
The baghouse contains seven sections of 160 bags each, six sections being used for fuming furnace gases and one for fume from the deleading kilns. A fan between the baghouse and the 300-ft concrete stack keeps the inlet side of the house under enough draft to prevent leakage from the screw conveyers beneath each chamber.

Continuously operating screw and drag conveyers carry dust from the boiler, flues, U-tubes, and baghouse to the deleading plant, where 3 to 4 pct slack coal is added before charging to the kilns. The two kilns are 5½ ft ID and 75 ft long, gas fired and operate at 2500°F at the discharge. Lead is reduced from 8 pct in the feed to less than 1 pct in the product, which is shipped to the electrolytic plant at Corpus Christi.

The fuming furnace is completely water-jacketed, 8 ft wide, 21 ft long, and 33 ft high, with 21 tuyeres on each side. Air at 10-lb pressure is supplied by a turboblower at a rate of 18,000 cfm. Two of three unit coal pulverizers are operated, grinding low-volatile coal from eastern Oklahoma which carries more than 70 pct F. C.

Four 12-ton ladles of blast furnace slag make up a furnace charge. Blowing time averages 100 min. At the end of the blow, the slag is tapped into a gas-fired settling furnace where a matte, carrying 50 pct of the copper and 70 pct of the gold and silver in the original slag, separates and is transferred to the converters. From the settling furnace the spent slag is taken hot to the dump.

Water used in the plant carries over 200 ppm of chlorine. Before the slag fuming plant went into operation this gave no trouble, since enough of it went to the slag dump to prevent build-up in the sinter circuit. With slag fuming, however, most of the chlorine in the slag reaches the deleading kiln baghouse as lead chloride and is returned to the sinter plant where it quickly builds up to the point where satisfactory sinter cannot be made and grate bar corrosion is excessive. To correct this condition, sinter baghouse dust carrying in excess of 5 pct Cl is leached with soda ash. The leach water carries the chlorine as NaCl to waste, and the filter cake, averaging 1.5 pct Cl, is charged to the blast furnaces direct.



Double bank of cooling tubes at the slag fuming plant.

Waste heat steam, 45,000 lb per hr from the reverberatory and 60,000 lb from the fuming furnace, is sufficient to supply power for all plant requirements with some excess for sale to the local power company.

At the present time, new material to the lead plant averages about 30,000 tons per month with about the same to the copper plant. Lead bullion produced amounts to 7500 tons per month, copper anodes 6000 tons per month, and deleaded zinc fume 3500 tons per month, near full capacity for all units. The entire plant operates seven days per week on a three-shift per day basis with a 40-hour work week. Total number of wage empolyes is 800, with 150 salaried employes.

El Paso Operating Statistics For January-June, 1956

Copper Operation

	Tons Smelted
Concentrate	14,500
Sulfide ores	1,500
Purchased mattes	2,700
Zinc residue	1,300
General copper ores	800
Silicious ores	1,900
Scrap copper	300
Limerock	2,900
Converter silica	4,300
	29,300

	Pb	Cu	Fe	S	
Matte (avg.)	4.4	43.6	23.3	23.4	
Anodes produced					5,400

	SiO₂	FeO	MnO	CaO	MgO	Al₂O₃
Slag (avg.)	40.1	35.9	1.1	10.1	1.5	6.8

Slag Fuming Operation

	Tons	Pct Pb	Pct Zn	Tons Pb	Tons Zn
Slag treated	19,252	1.59	16.2	306	3,119
Coal consumed	3,650				
Raw dust produced	4,147	7.16	66.1	297	2,741
Deleaded dust	3,451	0.96	77.47	33	2,673
Kiln baghouse dust	468	54.47	13.22	255	62
Dezinced slag	14,893	0.06	2.56	9	381

Dross Reverb Operation

	Smelted Tons	Pct Pb	Tons Pb	Pct Cu	Tons Cu
Dross	6694	56.0	3750	28.8	1927
Soda ash	295				
Sinter baghouse dust	21	50.0	10		
Coke breeze	52				
	7062		3760		1927
	Produced				
Lead	3575	97.5	3490	2.0	75
Speiss	1542	6.9	106	67.2	1035
Matte	1581	9.1	144	51.2	809
	6698		3740		1919

Lead Blast Furnaces

	Sinter	Charged Direct Smelting Material				Coke
Tons	29,300		390			3,395
		Produced				
	Tons	Pct Pb	Pct Cu	Pct SiO₂	Pct FeO	Pct CaO	Pct Zn
Lead	7,122	99.6	0.03				
Dross	6,694	56.0	28.8				
Slag	18,140			22.7	30.3	17.8	16.2

The San Manuel Smelter

The first suspended arch reverb in the Southwest and improved materials handling are here reported on, after a year's operation.

by R. C. Wilson

FACILITIES of the San Manuel Copper Corp., San Manuel, Ariz., were designed to produce approximately 12,000,000 lb of copper each month. Modifications of well established principles were made only to meet the requirements unique to the San Manuel project.

Absence of impurities in the ore body, and a concentrate whose copper content varies within narrow limits, makes the smelter metallurgy relatively simple.

Concentrate handling and storage

The partially dried concentrate, containing 9 to 10 pct H_2O, comes from the mill to a 3000-ton receiving bin. Six belt feeder conveyers under the storage bin discharge the concentrate onto a 24 in. belt for transportation to the main smelter building. Four 500-ton flux bins can feed individually or in combination, upon the same conveying system to make the prepared charge for the reverb.

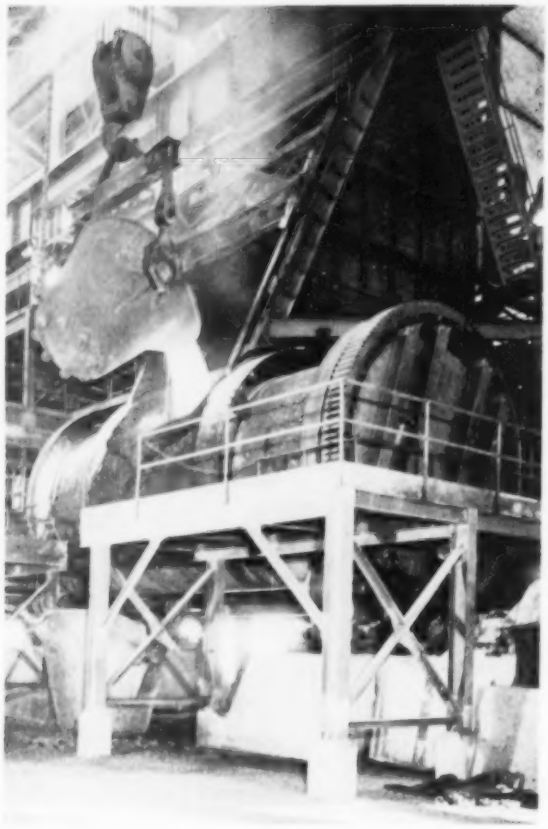
Fluxes

The converter flux is a mixture of oxide ore and quartzite, proportioned to make an average mix of 70 to 72 pct SiO_2. Mixed converter flux is transported to the main building where it is directed to the receiving bins above and behind the converters.

Limerock only is added to the concentrate, in an amount equal to 7 pct of the concentrate. About 3 tons of quartzite per day are used for fettling the reverb burner wall. Limerock and quartzite are mined about 14 miles north of the plant area. Oxide ore is supplied by the open pit mine, 8 miles away.

Reverberatory furnace

Concentrates are not roasted but are smelted directly in the reverberatory furnace. Prepared reverb charge is received in two 500-ton hoppers above the furnace, at the uptake end. These hoppers are located one on each side of the furnace and discharged onto individual tripper conveyers that unload into 24 fettling hoppers on each side of the furnace. Fettling hoppers are not used for storage but only to direct the charge into the furnace and to collect the dribble on the return side of the conveyers, thus reducing the dust on the furnace roof.



The reverb is 102 ft long and 32 ft wide, inside of the brickwork. In the combustion zone, the roof bottom is 11 ft above the hearth line. About 40 ft from the burner end, the roof slopes downward until it is 9 ft above the hearth line; this elevation is maintained back to the uptake. Crucible walls are 4 ft thick and are corbeled back to a sidewall that is 18 in thick. In the smelting zone, or the first 72 ft from the burners, the sidewalls are topped by steel cans filled with magnesite grains. These cans, 27x20x8 in. form the junction between the top of the sidewall and the furnace roof. Their purpose is to facilitate sidewall repair at the point of most rapid deterioration.

The interior face of crucible and sidewalls is lined with basic, steel-incased brick. Outer veneer of the walls is of silica brick. The entire roof and double uptake flue are of suspended basic tile. The side walls of the uptake are also suspended basic brick. This is the first suspended arch furnace to be used in the Southwest.

After eleven months of operation, there have been no maintenance or repair costs chargeable to the furnace refractories.

Copper water jackets are used at the slag line beneath the burners and around the settling zone, but not along the sides where the walls are protected by the charge piles.

Matte can be taken from the furnace through two tap holes on each side of the furnace at the uptake end. The matte ladles are transported to the con-

R. C. WILSON is Smelter Superintendent, San Manuel Copper Corp., San Manuel, Ariz. Paper presented at the AIME Annual Meeting, New Orleans, February 1957.

verter aisle on electrically operated cars that move on standard gauge railroad tracks along each side of the furnace. Reverb slag can be skimmed from either side of the furnace and is carried to the slag pile in four 225-cu-ft slag cars hauled by 25-ton diesel-electric locomotives. Converter slag is returned to the reverb through a pair of launders in the burner wall.

The reverb is fired by natural gas, through eight multiple-jet burners. Each burner has 84 ports and is operated at 7½ psi. Combustion air is admitted to the burners at 2½-in. H_2O pressure. The combustion air can be preheated to 700° F in a separately fired preheater.

Waste heat from the furnace is recoverd as steam in two boilers. There are no baffles in the boilers and exhaust gases have a nearly straight passage from furnace burners to the boiler outlet flue. Steam is produced at 475 psig and 725° F. At the maximum smelting rate, the boilers will produce over 100,000 lb steam per hr.

A control center in the smelter regulates the combustion conditions and draft on both the reverb and air preheater. Boiler operations, including automatic soot blowing, are also controlled from this point.

Construction and installation of furnace bottom

The reverb is supported upon a foundation that rises 10 ft 5 in. above the converter aisle grade line and extends 5 ft beneath it. The foundation consists of sidewalls, end walls, and bottom, of reinforced concrete, which form a tank 119 ft long and 39 ft wide by outside measurements. The interior of the tank is filled to the top of the concrete walls with tamped clay. The refractory walls of the furnace rest upon the concrete walls of the foundation.

Between the refractory walls, and above the clay base, magnetite sand was tamped into place to a depth of 5 ft. This formed the subhearth of the furnace.

Cooling tubes pass horizontally from sidewall to sidewall through the concrete foundation. These tubes have 6 in. diam and are situated 6 in. below the top of the clay fill on 18-in. centers. They are open at both ends to allow heat radiation from the bottom by natural convection. Six thermocouples spaced along the center line of the furnace record the bottom temperature in the control room. Should any thermocouples indicate furnace bottom failure by a sudden rise in temperature, cooling air can be blown through the tubes in the danger zone.

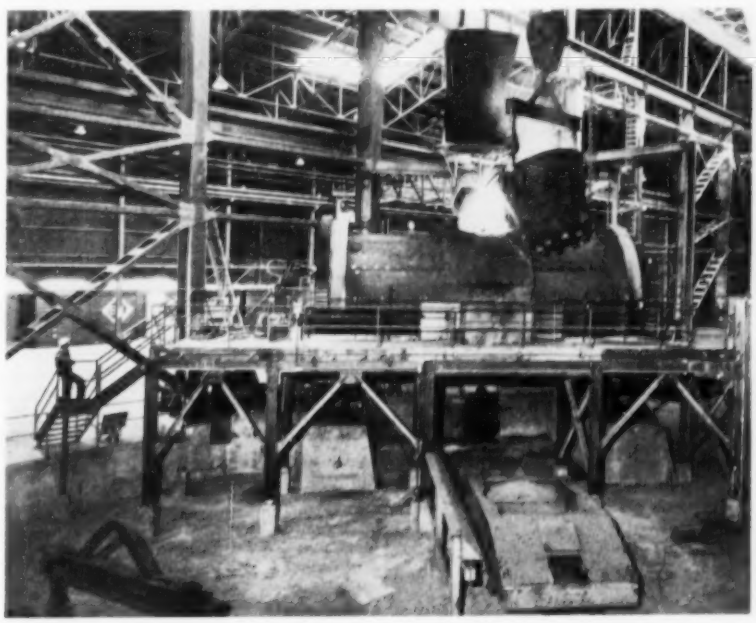
In December of 1955, the air preheater was started and the temperature gradually increased. The main burners were then ignited and the temperature further increased until all eight burners were operating at maximum capacity, exit gas temperature had risen to 2500° F, and the arch at the middle of the furnace was at 2650° F. This operation took 11 days.

At this time, 250 tons of converter slag, blown to contain a maximum amount of magnetite, were charged into the furnace. The slag melted rapidly and flowed out over the magnetite sand in a pool 6½ in. deep, and the operation was completed in 7 hr. The firing rate was then gradually reduced until temperature of the uptake end wall was 1800° F. This was maintained for eight days to allow the slag to cool slowly and anneal with a hard dense texture. Thus the operating hearth level was formed.

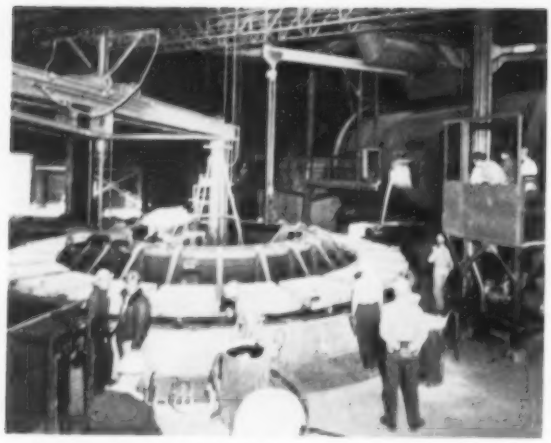
During annealing, a few contraction cracks appeared, but they closed and healed themselves when the temperature was raised again prior to introducing the first smelting charge. Smelting began on the morning of Jan. 1, 1956 and the first copper was cast on Jan 8.

After three months of operation, it was found that the furnace had moved 1¾ in. toward the converter aisle and ½ in. toward the boilers.

Deep bath smelting is practiced at San Manuel, the bath being maintained between 37 and 40 in. deep. Soundings have indicated that there has been no bottom build-up above the normal hearth line at the uptake end of the furnace. At the present time, the bottom has built up about 12 in. at the firing end. Experience has shown that this build-up can be melted out by regulating the preheated air temperature; however, excessive temperature in the fettling chutes then occurs.



Blister copper being charged into the rotating anode furnace. Gas burners are located in each end of this furnace, and poling is also done through the end.



Seven hundred lb anodes being cast on the 34-ft casting wheel.

Converters

There are three standard Pierce-Smith converters, 13x30-ft, equipped with 48 tuyeres. The tuyeres are of 2-in. tubing with 1.72 in. ID. Blast air is supplied by two blowers. Each blower can produce 30,000 cfm at 15-lb pressure. Blast air can be delivered to any of the three converters from either blower. In our normal maximum operation of two converters at one time, each converter will have a separate blower. The blowers are located in the powerhouse and are controlled at the converter platforms. A pulpit control panel at each converter controls air pressure, idle and blow, blast gate valve, as well as the uptake damper, hood door, and flux conveyors. The panels also contain an air flow indicator, air failure alarm, and converter rotation control. An air pressure gage and temperature recorder are mounted beside the panels. The temperature recorder is operated from an optical pyrometer that sights through the uptake onto the bath. A high temperature alarm from the optical recorder is located in the foreman's office. An air flow indicator, located for the convenience of the punchers, is mounted in back of the converter. The air flow is also recorded in the foreman's office.

Converter flux is introduced through the side of the uptake by means of a conveyor belt and chute. Punchers platforms are adjustable to desired height and are operated by air cylinders.

Flue dust

Exhaust gases from the converters are handled in an insulated balloon flue that joins the reverb flue in back of the waste heat boilers. Mixed gases are treated in a nine-unit electrical precipitator before being discharged to the atmosphere through a 500-ft stack.

Dust that settles in the balloon flue immediately in back of the converters is moved by screw conveyers to three storage hoppers. This dust is drawn out into trucks and sent to the converter aisle where it is smelted with the reverts, or it can be taken to the concentrate bins for smelting in the reverb.

Other dusts from the balloon flues are conveyed to a central point where they are joined by boiler dust and cottrell dust. These dusts are then moistened with water and put through a pug mill. The pugged dust is sent by conveyer belt to the concentrate charge storage bins above the reverb. All dust movements ahead of the pug mill are made by screw conveyors. About 700 lb of dust per day is removed by hand from the boiler ash pits.

Anode furnace

Blister copper from the converters is received in a 13x30-ft anode furnace. This vessel is a rotating, or converterlike, furnace and is fired by gas burners at each end. The receiving spout is located in the center and serves as a stack for exhaust gases, which are vented to atmosphere. Poling of the charge is done through one end of the furnace.

Anodes weighing 700 lb are made on a 34-ft-diam, hydraulically driven, casting wheel carrying 22 molds. The molds weight 5700 lb each. Pulverized silica is used for mold wash.

The casting wheel is operated from an enclosed, air conditioned, booth where the wheelman controls the tilting of the anode furnace, pouring spoon, and movement of the wheel. The wheel is positioned for each pour by an automatic limit switch arrangement in the hub. The anodes are removed from the wheel by air operated tongs and deposited in bosh tanks for cooling. An overhead crane removes the anodes from the bosh tanks to a rack holding 45 bars.

Operations

The smelter has been operated on a six-day week since the reverb was first charged, 11 months ago. During that time the equipment has demonstrated the capacity to produce in excess of the planned 12,000,000 lb of copper per month. When sufficient materials were available, the reverb has smelted in excess of 1000 tons of concentrates per day. Converter operations have varied between one converter per day and one and two thirds converters per day, again depending upon the availability of material. Copper casting has been conducted three or four times per week, on day shift only. The largest single pour contained 309 tons of copper.

San Manuel Operating Statistics For October 1956

Converter Dept.

27.5 Operating Days	
Matte converted, tons	13,926
Flux, tons	6,199
Blister produced, tons	4,443
Blister per converter day, tons	136

Reverb Assay, Pct

	Cu	SiO2	Fe	CaO	Al2O3	S
Concentrate	26.75	6.2	28.8	0.6	2.0	30.0
Reverb slag	0.40	36.4	33.4	3.5	7.1	—
Matte	32.0	—	37.9	—	—	29.0

Converter Assay, Pct

	Cu	SiO2	Fe	CaO	Al2O3
Converter slag	1.6	27.5	44.9	—	—
Oxide ore	0.74	64.8	3.2	1.2	15.0
Quartzite	—	94.8	—	—	1.4

Reverb Dept.

25 Operating Days	
Concentrates smelted, tons	16,332
Limerock, tons	1,187
Silica (burner wall fettling), tons	106
Flue dust, tons	564
Total solid charge, tons	18,165
*Btu per ton of concentrate (x 1,000,000) =	5.7
*Btu per ton solid charge (x 1,000,000) =	5.1

Anode Dept.

19 Pours	
Anodes cast, tons	4,120
No. of anodes cast	11,788
Pct rejected anodes	0.25
Avg. weight per pour, tons	217
Pouring rate, tons per hr	37.7
Copper content of anodes, pct	99.81

*Includes fuel burned in the air preheater

Cominco's Zinc Melting And Casting Facilities

The largest installation for melting zinc cathodes in the world is a low-frequency induction melting unit, used in conjunction with the first mechanical casting machine for commercial production of high purity zinc slabs.

by J. H. Nicholson

COMINCO installed a low-frequency induction melting furnace, constructed by the Societa Italiana Costruzioni Elettrotermiche of Milan, Italy, and a straight-line inclined casting machine, manufactured by Sheppard and Sons Ltd., Bridgend, Glamorgan, Wales, in 1953 in the Zinc Dept.[1]

The S.I.C.E. 60-cycle core-type induction melting furnace[2] is of the multiple chamber type, as distinct from the submerged resistor type.[3]

The furnace installed at Cominco has three in-line hearths with two furnace transformers between and twelve channels connecting the first and second hearths, and a similar arrangement between the second and third hearths. Cathodes are charged at two places in each hearth, and molten metal is withdrawn from the center section of the third hearth.

The Sheppard casting machine operates in conjunction with the induction melting furnace. Experimental work on a wheel had been carried out previously, which indicated that mechanical casting was feasible. The straight-line inclined machine was thought to have certain advantages and the results have been gratifying.

Molds are carried on an endless conveyor chain, so that empty molds pass successively under a ladle straddling the lower or trailing end of the machine immediately adjacent to the third hearth of the melting furnace. Molds are filled with zinc pumped from the furnace, as they pass under the ladle. The zinc solidifies as the molds travel up the incline and the slabs are discharged at the head end.

Construction of furnace

The space occupied by the furnace proper is 21x 25x7 ft. Crane clearance for charging cathodes is required above, and access is needed below for cooling air ducts and bus bar feeders. Step-down transformers, regulating transformers, and oil circuit breakers are housed in fire-proof vaults above and adjacent to the furnace. The operating panel board is on the main floor level. The condenser bank is housed in a separate room under the panel board. The fan room is on the basement level, to one side of the furnace.

The sides and bottom of the steel shell are lined with asbestos mill board cemented in place. The base brickwork of each hearth is built up with standard insulating and fire brick. Special heavy duty refractory shapes are partly imbedded in the brick floor. These shapes are interlocking and serve to key in place the massive cathode bearing blocks.

Each of the four furnace transformers consists of three induction coils, and each coil is set into a split bronze bushing. The bronze bushings are bolted to, but insulated from, a heavy steel support plate, which in turn is bolted to, but insulated from, the main floor steel. Precast refractory slabs are spaced between the center bushing and the two outside bushings. The bushings are covered with transite side plates; the whole bushing is wrapped with asbestos cloth and bound with a cotton tape. The open top of each bushing was closed with a temporary plate while construction was in progress to prevent deformation during the subsequent ramming operations.

The successful operation of the furnace is dependent on the correct placement of a dense, impervious, homogeneous, monolithic lining forming the crucibles and channels, which will hold the molten zinc. To attain this it is imperative to pay the strictest attention to proper preparation and placement of the refractory, to observe strict cleanliness throughout the operation, and finally to dry and bake the lining under controlled conditions.

The materials used for the final lining are an equal parts mixture of ZN and ELO grades of ramming aggregates, and a sulfite liquor for the binding agent, all purchased from Didier Werke, Weisbaden, Germany.

Prepared mix was spread loosely to a depth of 3 to 4 in. in the sections to be lined. All surfaces in contact with the lining were given a heavy brush coating of sulfite liquor. Ramming commenced immediately, with as many moisture-free, air-operated hammers as the working space would permit. Rapid short passes were made in all directions within the working area of any one hammer. A loose layer of the mix was maintained on the working face at all times to avoid polishing, which can lead to laminations in the mass. The required depth was built up by adding fresh mix to the working face. Placement started in the hearth areas first, and proceeded to the more critical channel areas between the bronze bushings. This work was carried on without interruption until the complete floor had been rammed.

After the floor had been leveled, the wooden channel formers and sidewall formers were placed in position and placement of the second batch be-

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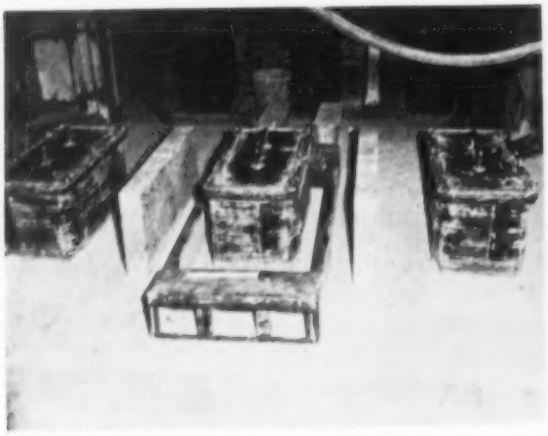
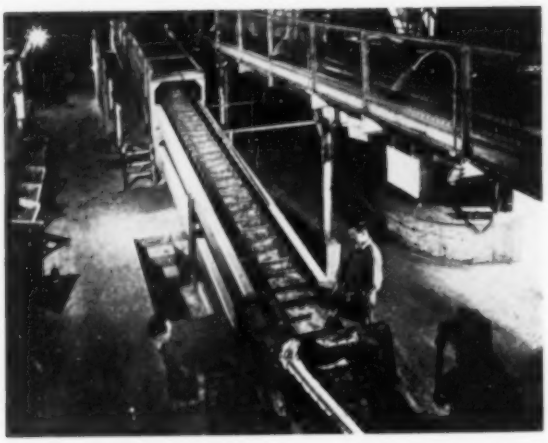


A furnace transformer section, showing wooden channel former in place on the rammed floor. The formers are slotted to carry copper flat bars used in baking the lining.



General view of the Sheppard casting machine, showing zinc flowing in asbestos cloth lined launder to the ladle mounted over trailing end of the mold conveyor.

gan. The thin channel walls are the most critical part of the furnace, and ramming in these areas was done with extreme care and thoroughness. On completion of the ramming, the sidewall formers, which were made so that they could be knocked down, were removed, but the wooden channel formers were left in position. The surface was given a heavy brush coating of sulfite liquor. The refractory lined furnace top was bolted to the sidewalls, and other miscellaneous work completed as quickly as possible.

Power

Main 60-cycle power is supplied to the step-down transformer vault at 2200 volts, through a Westinghouse DE-ION GRID oil circuit breaker which can only be closed at the breaker board, but can be tripped out by a knockout switch on the furnace operating panel board. A 110/220-v transformer which is tapped off before the oil circuit breaker, feeds a lighting panel, a 24-v battery charger for the oil circuit breaker control, a 220-v supply for the closing motor of the oil circuit breaker, and the step-down transformer bank temperature alarm.

The 2200-v line feeds three 1500kva 2200/600-v, 60-cycle, single phase, water-cooled Packard transformers. The 600-v secondary feeds four 750 kva 60-cycle, 3-phase, 10-step, regulating transformers, made by Emile Haefely et Cie, Basle, Switzerland, through a 2000-amp air circuit breaker, and four Oerlikon oil circuit breakers—one for each regulating transformer. The tap selector mechanism and Oerlikon oil circuit breakers are operated by push buttons at the furnace panel board.

Each of the four three-phase furnace transformers consists of three induction coils complete with laminated iron cores, and connecting top and bottom yokes. The induction coils are set into the split bronze bushings between the hearths.

Each coil has several connections which permit a six-step change in the number of windings, and with the ten-step regulating transformer, 60 power changes are available. Thus, for four coils, there is a total of 240 power inputs available, if desired.

Cooling air to the induction coils is brought under the furnace from the fan room. Two fans supply the cooling air for each furnace transformer through three ducts, each leading to an induction coil. The spent air is exhausted through louvres above the tranformers.

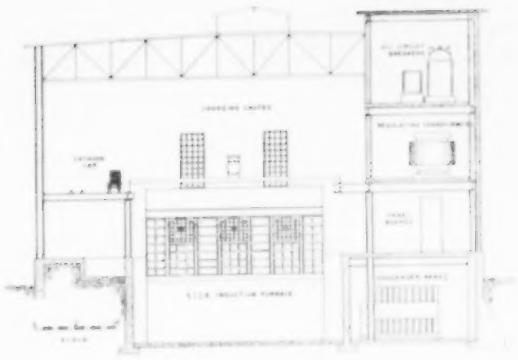
The regulating transformers and cooling air fans are interlocked so that the Oerlikon circuit breaker cannot close unless the fans are operating; in the event of fan failure, the oil circuit breaker is opened, taking the transformer off load.

For main power interruptions, emergency power for two cooling air fans for all the furnace induction coils is provided by a generator powered by a battery-started Chrysler gasoline engine. Each control cubicle has an indicating recording kw meter, an integrating kw-hr meter, an ammeter for each induction coil, a frequency meter, a power factor meter, and a volt-meter on the secondary of the regulating transformers. Each condenser bank consists of fifty 20-kvar units made by Emile Haefely et Cie, sufficient to correct the power factor to 0.9 at 450 kw. Two fans supply cooling air to the condenser room.

Drying, baking, and charging

Before starting up the furnace the rammed mix lining was dried and baked carefully. Laboratory studies indicated that the true moisture content of the mix as prepared was 6.7 pct of which 1 pct was considered water of crystallization. Heat was supplied by resistance and induction. Weep holes were provided in the sides and bottom of the steel shell.

The wooden channel formers are made with a slot to take a copper flat bar, and a circuit was completed around each inductor coil by joining each two bars with a short copper connector. These connectors completed the secondary winding of the furnace transformers. When power was applied at the panel, a current was induced in the copper loops, and the heat generated burnt out the wooden former and baked the channel section. At the same time the hearth sections were heated by a total of 120 kw of resistance heaters, made up of 12 units with four units in each hearth. Heat was largely confined to the rammed mix by building a false sheetmetal cover over the crucible and insulating this cover. The power on all the furnace transformers and resistance heaters was gradually raised. A temperature of about 1570°F was reached, at which point the resistance heaters collapsed. The resistance heater units and



End elevation of S.I.C.E. furnace, showing location of oil circuit breakers, regulating transformers, panel boards, and condenser banks.

copper flat bar loops were then removed from the furnace as quickly as possible, and the furnace charged with molten zinc to a level above the channels, by laundering zinc from another furnace. Sufficient power was kept on the furnace transformers to keep the zinc in the furnace molten.

Cathodes are charged in 1100-lb bundles from the top of the furnace through vertical shafts at two places in each hearth. One side wall of the upper part of each shaft is fitted with a hinged section which opens up to form a horizontal platform. The cathodes are transferred by crane operated tongs from flatcars to a platform, which tilts and discharges the cathodes into the shaft. Thus there is a column of cathodes on edge extending down from the charging platform on top of the furnace, through the bath, to the bottom of the furnace. The lower end of the cathode column rests on the cathode bearing blocks on the floor of the furnace. These blocks have raised projections which allow a circulation of molten zinc under the column. Hot molten zinc from the channels circulates around the submerged section of the column, which gradually sinks as it melts.

Mechanical Casting

Mold conveyer

The overall length of the single mold strand Sheppard casting machine is 60 ft. The conveyer chain, carrying 140 molds, consists of two strands of steel links and hardened rollers with angle brackets welded to the sides to carry the molds. The molds are held firmly in place by means of pins which pass through the brackets on the chain and the lugs on the molds, and are slotted to receive tapered steel wedges. Molds are easily changed by removing the wedges and pins. The molds are cast with a lip on the trailing edge so that each lip overlaps the next mold in succession; this provides a spillway, should overfilling occur.

The flanged wheels on the mold conveyer chain roll on flat steel tracks attached to the machine frame. Both sets of molds, that is, the loaded molds and the return molds, are carried on top of the tracks. The tracks are not continuous as there is a gap at both ends to allow the wheels to cross over.

Drive

The mold conveyer is driven by a booster driving unit through a Vulcan Sinclair Scoop Control Variable hydraulic coupling, a worm reduction gear unit, and machine-cut spur gearing. The booster unit is driven by a 10-hp 900 rpm motor, and is mounted beneath the machine near the head end on a separate foundation. The actual booster chains are made of hardened steel bushed rollers and links, fitted with driving teeth which are formed to engage evenly with the bottom strands of both mold chains. This caterpillar type drive engaging the returning empty mold chain transmits a uniform horizontal motion and eliminates the chordal action which occurs to some degree in the normal head drum drive mechanisms. It produces a smooth transmission which is essential if the surface of the zinc slabs is to be free of ripple and shudder marks.

Casting

Molten zinc is delivered to the ladle by means of a pump discharging to a launder. The zinc is lifted approximately 7 in. above bath level, and discharged to a launder made of half a 4-in. steel pipe lined with cotton-free asbestos cloth.

The open launder leads to a discharge launder made of 4-in. steel pipe mounted on the casting machine above the molds. A steel plate ladle hangs centrally over the mold travel, being a section of a cylinder of 7½ in. radius and 15 in. long. Between the points of suspension, the side of the discharge launder away from the pouring edge of the ladle is cut away, and a spillway fitted, which allows the molten zinc flowing down the launder to enter the lower part of the ladle. All parts of the discharge launder and ladle in contact with molten zinc are lined with asbestos cloth. Ladle action is controlled manually by a wheel through mechanical linkage. The ladle operator adjusts the flow of zinc by push button speed control of the pump motor. This ladle is simply a means of distributing the flow of zinc uniformly over the mold, and is a convenient method of effecting a cut-off between molds; it is not designed as a reservoir of zinc, and normally contains less zinc than would form one 56-lb slab.

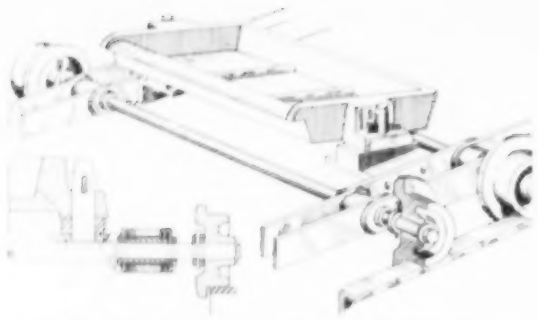
Immediately after the zinc is poured, the froth on the surface is skimmed off and disposed of in a separate container. The metal skimmings are charged at intervals to a scrap furnace producing a lower grade of zinc.

Cooling

The skimmed surface of the zinc is cooled by a stream of compressed air from an air header. The air cooling freezes the surface of the slabs giving a relatively smooth plane surface. The molds are cooled on the underside with water from low pressure water fountains. A collecting pan is fixed under the mold strand in this area, and collects the run-off water and conducts it to the sewer.

Discharge

After passing through the water cooling section the molds are near the head of the casting machine. A hammer, geared to the head drum shaft, raps the side edges of the molds as they leave the horizontal travel. A second hammer also driven from the head



Sketch of the mold and chain assembly on the Sheppard zinc slab casting machine. The detail view of the mold chain in the lower left shows how the molds may easily be removed by simply taking out the tapered steel wedges and removing the pins.

drum shaft gives each mold another rap as it is just past the vertical position. The slabs fall out onto a sloping chute and come to rest against a damped bumper bar on a roller conveyer mounted at right angles to the chute at a convenient height for hand stacking in 50-slab packages on both sides of the roller conveyer.

Operation

At Trail, where relatively low cost electric power is available, the advantages of an integrated operation of induction melting and mechanical casting include improved operational control and improved working conditions. Melting and casting is a continuous operation over a 24-hr period. The casting rate is adjusted to suit the melting rate of the furnace, which in turn is dependent on several factors of which the most important is the daily production requirements.

By induction heating, the heat is produced in the metal itself, and can be controlled to give a uniform temperature consistent with good casting technique. It avoids subjecting the metal to high temperature combustion gases which would tend to oxidize it and promote metal losses, and eliminates hot combustion gases with attendant extensive flue systems and dust catching equipment.

The furnace holds about 80 tons of zinc. There is sufficient transformer capacity on the furnace to melt at least 450 tons per 24 hr.

Power consumption of the furnace transformers is approximately 106 kw-hr per ton of zinc slabs produced.

Dross is a nuisance in any melting operation, but to some extent it is useful in induction melting. The electrodynamic forces set up in the molten zinc aid in allowing the dross to come to the surface, and a fairly heavy dross layer is maintained on the molten zinc to conserve heat. The dross layer is worked frequently with long steel rabbling irons through dross doors provided in the sides of the furnace. Ammonium chloride is used as a drossing agent to free the entrained metal from the dross. Dross is pulled from the furnace into dross buggies several times in each shift, and is dry enough to be used in a subsequent roasting operation without the usual treatment in dross drums. Dross production averages 2.5 to 3.0 pct of slab zinc produced.

The hearth sections of the furnace are ventilated through the roof by an exhaust fan, which also ventilates the cathode charging shafts. The dust burden in the exhaust gases is small, being in the order of 150 to 200 lb of dust per day, assaying 60 pct Zn.

The capacity of the Sheppard casting machine is adequate to meet the melting rate of the furnace at production rates up to 450 tons per day, and here again a high degree of flexibility in casting rate is available through the variable speed hydraulic coupling. The nine-man shift crew is under the supervision of a chief operator.

There are two drossers, two chargers, one caster, one skimmer, and two stackers, and this crew, with the exception of the drossers, rotates.

The most serious maintenance problem on the furnace was due to refractory failure in several channels some months after starting up. One furnace transformer was put out of commission completely, and one induction coil in another furnace transformer was inoperative, so that this transformer operated at reduced load. Under these conditions the furnace production averaged some 240 tons per day, and on one day, produced 313 tons in a 24-hr period. An attempt to repair the damaged channels without emptying the furnace was not successful. The rammed mix lining in the failed channel sections was dug out, and rerammed, but failure again occurred shortly after restoring the power load. The furnace was relined completely in the summer of 1955. Although it was difficult to state with any degree of accuracy the actual cause of failure, there is a strong feeling that it was due to improper placement of the rammed mix, inferior quality of the special refractory shapes, and incomplete baking of the lining.

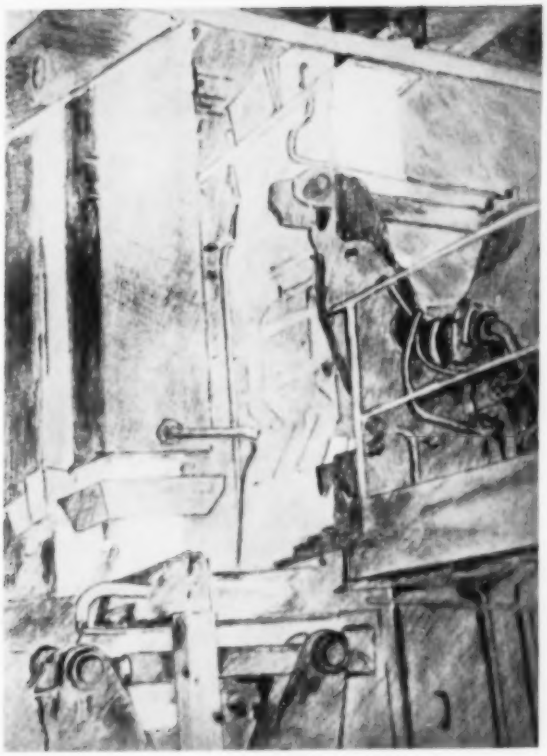
References

[1] *Canadian Mining Journal*, vol. 75, no. 5, May 1954, p. 280.
[2] M. Khek: Canadian Patent 518,391, Nov. 15, 1955; U. S. Patent 2,673,229, Mar. 23, 1954.
[3] M. Tama: *AIEE Electric Heating Conference*, April 1955, p. 62.

Operating Statistics for S.I.C.E. Furnace at Three Different Rates

Section	October 11, 1955				November 25, 1955				January 19, 1956			
	1	2	3	4	1	2	3	4	1	2	3	4
Induction coil turns	43½	43½	43½	43½	41½	41½	41½	41½	38½	38½	38½	38½
Regulating transformer tap	10	10	10	10	10	10	10	10	10	10	10	10
Regulating transformer, v	600	600	595	595	595	595	580	585	580	580	570	570
Induction coils, 1 amp	400	400	420	400	480	470	500	475	625	610	635	605
2 amp	480	505	500	480	500	545	535	530	595	635	645	640
3 amp	260	300	300	280	300	305	335	305	400	390	440	440
Power factor	0.986	0.986	0.990	0.975	0.985	0.990	0.980	0.995	0.860	0.885	0.865	0.920
Kilowatts	420	425	430	430	440	450	460	465	480	480	500	520
Bath temperature, °F	865	865	880	880	875	875	895	890	855	875	885	880
Slab zinc produced, tons	377				413				449			
Power, total kw-hr	40,269				42,520				46,030			
Power consumption, kw-hr per ton	107				103				102.5			

Continuous Steel Casting In France



Translated and Summarized

from an Article by Rene Fievet

THE decision, regarding the installation of a continuous casting plant at Cail was made in 1952, after a study of existing installations in the U. S., Germany, and Austria.

The means for the production of steel include an open hearth and an electric furnace shop of an annual capacity of 85,000 tons, oriented toward the production of special quality steels for processing in a medium and large forge shop, a foundry, and a mechanized thin sheet rolling mill.

A quantity approaching 2/3 of the total tonnage is destined for the rolling mills. The metal is, therefore, cast into ingots 250 mm sq weighing some 600 kg, which corresponds to the maximum possibilities existing for the transformation of semi-products.

The necessity of utilizing small ingots resulted in a high cost for the semi-products from the three-high mill. It could easily be imagined that the process for the hot rolling of fine sheets risks being completely outside of competition, with the exception of some special qualities of steel. The project put forth, therefore, consisted of modernizing the rolling mill. It included two distinct stages: a) installation of a continuous casting plant supplying slabs to a planitary hot rolling mill of the Sendzimir type, permitting the rolling of coils, and b) a reversing cold strip mill, also of Sendzimir design.

The Cail installation, Europe's largest

The continuous casting installation at the Cail steel plant actually includes two Junghans machines located adjacent to one another with their casting floor 17 m above the floor of the steel mill. Each machine includes two casting molds so that there are four casting lines. The molds are copper with a water jacket on the outside, about 1 m long.

Experiments have been conducted on three types of molds: a) Molds built of four copper plates cooled by external water circulation; water flows through laminations a few millimeters thick under a pressure of 4 kg at the inlet; cooling is good, but there are risks of water leaking into the steel along the plate joints. b) Molds with water circulation inside the copper wall; water circulation is much nearer to the side in contact with the steel; this part of copper, very thin, undergoes aging phenomena and is liable to crack; tightness is better when this mold has just been put into service, but the mold life is much shortened. c) Copper molds cast in one block without any corner joints; these molds have led to the best results; water flow on each mold is controlled between 600 and 1100 liters per min.

At the bottom end of the molds, the product is subjected to a cooling by direct water sprays. The cast piece then comes in contact with the transport rolls, the speed of which is controlled by the operator on the casting floor. The slabs or bars are cut into lengths of 1.6 m corresponding to the size of the reheating furnace, but plans are in hand for the digging of a pit under the machines in order to permit cutting lengths of 6 m.

Another part of the installation consists of an inclined skip used to raise the teapot casting ladle to the height of the floor of the casting machine. The ladle and the feeding channels of the casting machine are heated to a temperature of about 950°C. The metal is poured from the ladle into a launder, each end of which feeds a small tilting trough which in turn feeds the two casting lines of one machine. The casting is thus done by free pouring, and dams in the liquid metal circuit limit the quantity of slag

RENE FIEVET is director of the Cail steel plant in Denain, France. Paper presented at the AIME Annual Meeting, New Orleans, February 1957.

carried along with the metal. It is, nevertheless, indispensable constantly to *pump* the surface of the liquid metal in the molds to remove particles of slag which are brought along with the metal.

In order to avoid oxidation, casting can be done under a reducing atmosphere — acetylene flame. Difficulties are experienced in the casting of aluminum-killed steel due to the formation of submerged crusts. Oil lubrication has been attempted through the use of oil drops on the surface of the steel in the mold. These drops roll off of this surface and insert themselves between the steel and the mold. However, no significant improvement either in the working of the installation or in the appearance of the skin of the slab was noticed. Moreover, oil smokes are a nuisance as they hamper the operator's view of the upper level of molten steel.

High production rates achieved

The casting speeds practiced at Cail have a maximum of 575 mm per min, permitting the casting of 60 metric tons per hr. The maximum casting speed is limited by the risks of longitudinal cracks or stress fissures in the core of the billet, if it is not solidified before reaching the pinch rolls. On the other hand, the speed must not be too slow because of the risks of a low metal temperature by the end of the casting.

The thickness of the solidified crust is about 32 mm at the bottom of the mold, and thorough solidification is completed only a short distance above the pinch rolls, 9 to 10 m under the mold. Beneath the mold each billet is sprayed by four banks of 12 nozzles, with a total discharge of about 90 liters of water. Under the spraying area the billets enter a sheath of falling water, where they are cooled by radiation only. The space between the billet and the wall of the water sheath is about 50 mm.

Flame cutting takes between 1 and 2 min for each billet. The torch is driven by a device synchronized with the driving motor of the pinch rolls. No powdered iron is used.

The casting plant is fed by ladles containing from 33 to 35 metric tons of metal. The total tonnage continuously cast at the Cail plant in 1956 was 65,000 metric tons, 2000 to 2500 tons being cast each month. Such a sustained rate of production is believed to be greater than that achieved in any other plant up to this time.

In order to make the operation completely continuous, studies are being made of the possibility of casting one ladle of metal after another, with a minimum of stoppage between operations.

Metallurgical results

The steels continuously cast at this plant include the following: mild steels, killed and rimming; high carbon grades; alloys of chromium, and molybdenum; and silicon alloys for magnetic sheets with carbon less than 0.08 pct and silicon between 0.6 and 1.6 pct.

Based on two years of practical experience, metallurgists at Cail believe that the average quality of the continuously cast products is at least equal to that of steels cast in the traditional manner. The following specific points may be made for continuously cast steel: 1) a tendency to have a more favorable primary grain size; 2) a more homogeneous distribution of segregations; and 3) a more homogeneous chemical composition in the transverse as well as in the longitudinal directions.

Heterogeniety at the center of continously cast bars of killed steel tends to be less favorable than those observed in similar ingots cast with hot tops in the ordinary manner. However, for the types of steel produced at Cail, a coeffecient of reduction on the order of four has produced a satisfactory central zone for forged and rolled products.

Table I. Control of the Chemical Homogeniety of Continuously Cast Bars, Medium Carbon Killed Steel, 240 mm Square

Position	C	Si	P	S	Mn
Vertical core,					
Beginning of cast	0.083	0.061	0.016	0.015	0.221
Middle of cast	0.083	0.056	0.017	0.015	0.221
End of cast	0.074	0.052	0.019	0.018	0.214
Cross-section,					
Middle of cast					
edge	0.083	0.056	0.018	0.015	0.221
center	0.074	0.056	0.020	0.017	0.221
opposite edge	0.083	0.056	0.017	0.015	0.221

It is certain, however, that to obtain satisfactory results, continuous casting requires strict attention to factors affecting the central part of the cross-section of the cast piece. In this regard the speed of casting and the temperature are paramount. Satisfactory experimental results appear to have been obtained with the Junghans-Schaaber process for the application of a circular magnetic field to the metal at the top of the mold. The movements thus created in the liquid metal result in a more compact central core in the cross section of the continuously cast bar or slab. This process has not yet received commercial application.

In respect to surface qualities, the continuous casting plant at Cail has achieved much more satisfactory results than are obtained with normally cast ingots. Moreover, the products of the continuous casting plant are generally delivered to the rolling mill or the forge without any preparation of the surface.

The inclusion count shows that the results obtained by the two methods of casting are practically equivalent. However, inclusions are distributed more uniformly in the continuously cast products.

Rimming steel cast by the process gives equally satisfactory results, and the experience in this plant shows that this type of steel can be cast just as well as killed steels.

Economic results

Saving in metal: It is clear that casting by the continuous method into long bars or slabs results in an important economic saving. In ordinary casting, it is necessary to crop the top and bottom of each ingot, but continuous casting allows a considerable reduction in this waste, for a piece must be cropped only at the beginning and the end of each casting period. An economy is also realized in the rolling of bars, for the continuously cast bar does not have bad ends which are inevitable with ingots. This results in greater efficiency of the rolling mill, which results in a production increase of up to 15 pct, or 30 kg per metric ton.

The metal recovery of a continuous casting installation would reach a maximum if the succession of the casting operations were such as to allow a 100-pct operation. This would be difficult to do, even with several furnaces, because of the risks of bunching the casting. It is indeed difficult to organize the operation of two furnaces so that castings follow one another without any interruption or jamming.

Saving in operating costs: If a comparison is made between the operating costs of a normal ingot casting bay with that of the continuous casting machine,

the results are as follows: First, the use of a continuous casting unit results in increased expenses with respect to man-hours, general repair costs, and cutting costs. Second, the operating costs for the continuous unit are less for refractories, ladle and mold heating, surface preparation of the cast products, and the molds. Leaving mold costs out for the moment, it appears that, for a production on the order of 3000 metric tons per month, the operating costs are identical for both processes. It is the opinion of Cail that this represents the minimum rate of economic production. As far as mold costs are concerned, continuous casting molds cost only one tenth as much as normal ingot molds required for a similar rate of production.

Saving in rolling mill costs: Economies in the rolling operation resulting from the installation of a continuous casting unit can be considerable, when the cross section of the cast product is studied with a view to reducing further transformation processes. The most typical case is that of hot sheets. The continuous casting unit can produce good quality slabs of which the maximum width has reached 500-mm in commercial installations and 1-m in a research unit. With the production of such slabs directly from the liquid metal, a slabbing mill with its high capital costs is no longer necessary. A similar situation exists with tube rounds, and for bars it appears equally possible, by designing a proper cross-section, to eliminate the blooming mill.

The future

It is possible to make certain predictions of the future course of the developments in continuous casting from the unit at Cail, which has been producing at a commercial rate for over two years. With this machine, the French metallurgical industry found itself at the head of the industrial development of this practice. Production at the rate of 45 to 60 metric tons per hr from a ladle of 35 tons has been realized.

A continuous operation: It must be admitted that, contrary to its name, the process is not continuous, but there are moves to confer on the operation a completely continuous character. In this regard, it may be possible to utilize a holding furnace somewhat similar to the classical mixer used for pig iron. But it appears that the quality of refractories currently utilized in a steel mill does not permit the use of such a mixer for molten steel.

Integration with large melting furnaces: With a view toward the integration of continuous casting into a normal-size steel mill, it is necessary to examine the capabilities of these casting units.

The results at Cail show that for the cross section adopted, a square of 240-mm, no difficulty has resulted in casting from furnaces of 40-metric ton capacity with a casting time of 40 to 50 min. This has been achieved with four casting units, but for a section of 100x1000-mm the same result might be obtained from two units. A casting plant double the size of Cail, casting similar sizes in 60 min from one ladle, appears quite possible. Such a continuous casting machine of eight units would be capable of casting a tonnage of metal on the order of 100 to 120 metric tons at one time. Thus, it appears that the rate of production of a continuous casting machine is capable of coping with the production from a steel mill with 100-ton melting furnaces.

Maximum machine capacity: In view of the discontinuous character of the operation, it is important to ascertain the maximum daily and monthly capacity of the casting machine. In this vein two points should be considered: First is the possibility for a steel plant of several melting units to realize a synchronized operation permitting the feeding of a casting machine with maximum regularity. Second is the minimum time required between castings to verify the state of the casting machine.

As to the first question, it might be possible to synchronize the production of melting furnaces as long as the types and qualities of steel are similar. Such a synchronization appears most possible with electric furnaces.

For the second question, Cail considers that the casting operation can continue with a maximum interruption of 15 min. In the case of certain types of steel, several castings can succeed one another without interruption outside of the time necessary for placing succeeding ladles into casting position.

These two answers permit the calculation of the maximum possibilities of the Cail installation, using one ladle of 35 tons cast per hr, 45-min casting time, and 15-min stoppage. This corresponds to 840 metric tons per day or 20,000 to 25,000 tons per month.

The problem of slab production from a continuous casting line is being studied at Cail, and from indications at the Canadian plant and the laboratory of Junghans in Germany it appears that slabs up to 45x1000-mm can be cast.

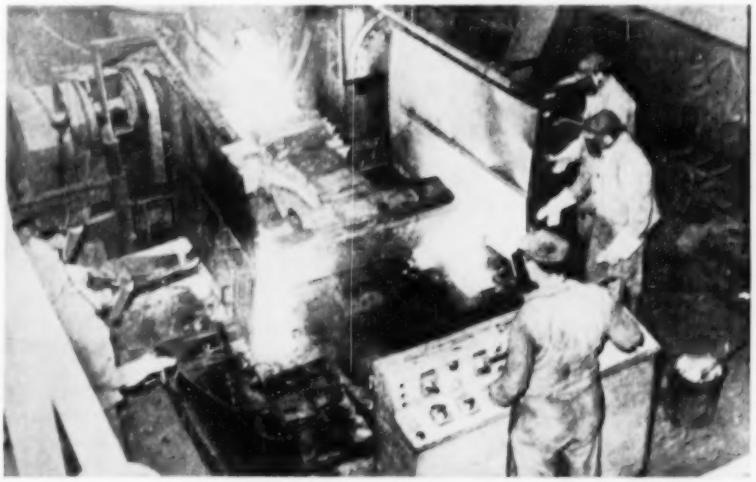


Fig. 2—Continuous casting in progress at the Cail plant in Denain, France. The operator controls pouring of the metal from the ladle into the launder and thence into the two molds.

Notes On Continuous Casting In Germany and Belgium

BASED on Junghans' pioneer work in Schorndorf, a one-strand continuous casting plant was built at the Mannesmann-Huttenwerke in Huckingen, where successful experimental work has been carried out since 1950. The types of steel cast there corresponded essentially to the production program of the electric steel plant, which is concerned principally with alloy tube steels. But killed and rimmed carbon steels and stainless steel were also cast, among others. In 1954, this first machine was converted into the first commercial four-strand plant in Germany.

This plant operates in conjunction with a 35-ton electric furnace. Even with limited production, valuable results have been achieved, especially with semiproducts for tubes, the principle product of this steel works.

Bottom pour ladles used

The Huckingen plant is the first to use the bottom-pour ladle, otherwise common in every steel mill; its capacity is 35 tons. One advantage of the bottom-pour ladle is that the temperature of the steel during pouring varies only little, 30°C being the maximum. However, it is necessary to cast at least 10 tons per hr for satisfactory operation.

Semiproducts for tubes produced

Up to now, the machine has been used mainly to make semiproducts for tubes. The usual sizes of the rounds are between 260 and 340 mm, but strands down to 130 mm are also produced. With still smaller sizes, the casting rate is too slow for production operations, or if the speed is artificially increased, the quality of the strand core is unfavorable for mechanical working. Casting rates at Huckingen are about 350 mm per min for 300 mm rounds, about 525 mm per min for 200 mm rounds, and about 1000 mm per min for 100 mm rounds.

Rounds can be worked directly on the Mannesmann and Pilger rolling mills, whereas rectangular strands, for example the frequently produced 200x240 mm billet, must first be rolled into a round of about 130 mm diam. Whether to cast round strands or slabs which require rolling into rounds depends upon the combined technical and commercial viewpoints. Moreover, in the case of small cross sections, quality is also decisive.

Casting speeds must be uniform

For core quality, it is important to keep casting speed as uniform as possible. For a particular strand size the maximum casting speed, above which longitudinal cracks form on the surface of the billet, depends on the pouring temperature, and the lower the temperature the higher the possible casting speed. Since temperature drop can be considerable during teeming with tipping ladles, the casting speed had to be increased with falling temperature. The difficulties connected with this, and particularly non-uniform quality of the strand core, are avoided by teeming with a bottom-pour ladle.

The four-strand Junghans machine

Directly under the copper molds, which are 1 m in length, the billets are subjected to direct cooling by the water sprays. Driving rollers are located 4.5 and 6.5 m below the molds. There are no other guide rollers on this machine. The mold is lubricated with an oil in order to obtain a good surface on the billet. At Huckingen, the billets are usually cut to 4-m lengths.

Plans are now being made at Huckingen for a new machine with eight strands. This machine will be operated according to a process which will allow a considerable increase in the casting rate. The new machine will be erected in an open hearth plant belonging to Mannesmann, and will cast charges of 75 to 80 tons. Killed carbon steels will be produced for tube manufacture.

An experimental continuous casting line for Belgium

At the Belgian National Center for Metallurgical Research, CNRM, at Charleroi, a new experimental continuous steel casting unit is being built according to British design.

The unit is designed to study the possibilities of continuously casting acid bessemer steels of killed and rimming qualities in industrial quantities.

The casting floor will have a height of 15 m. There are to be four independent casting lines, one of which will be put into service in 1957, producing bars from 90x90 to 125x125 mm.

It can be expected that commercial units will follow in due course in the Belgian steel industry.

An Efficient Method of Desulfurizing Liquid Pig Iron

by B. Trentini, L. Wahl, and M. Allard

REMOVAL of sulfur in steelmaking is presently a problem of utmost importance as requirements on final sulfur contents in finished steels become increasingly strict. This is in spite of often increased sulfur contents in the fuels used during the different stages of steel processing.

According to local conditions or current economic factors, sulfur can be removed during one or more of the processing operations; for instance, in a blast furnace operated under high temperatures and with a high slag basicity ratio and also by means of high inputs of manganese into the burden. These methods of proceeding are, however, expensive and in contradiction with the acid practice which is gradually being developed owing to the fact that it allows coke and lime savings and usually permits an increase of productivity.

In the melting-shop, desulfurization can proceed in the open-hearth or electric furnace with one or several very basic slags, or with special prefused slags (Perrin process) mixed with steels poured from the open-hearth, electric furnace, or converter.

Liquid pig iron has also been treated separately before being used in the melting shop, in order to reduce high sulfur contents. This external desulfurization has been developed in Europe for the basic Bessemer Thomas process, which is again in favor owing to the great flexibility of such installations and to the fact that the steel produced is not polluted by impurities coming from the scrap. Since the basic Bessemer process, as usually practiced, has a low desulfurizing power, external desulfurization is generally carried out in ladles by means of alkalies such as soda ash. This method, which has the advantage of being simple and costing little, has only a medium desulfurizing power, which implies the necessity for repeating the operation several times when a substantial amount of sulfur has to be removed or when very low sulfur contents are desired. Thermal losses are high and there is a considerable decrease in output. Moreover, the resulting fluid and corrosive slag, which is extremely difficult to eliminate, attacks the refractory linings of the mixers and steel furnaces.

Therefore, it seems necessary to devise a simple method for external desulfurization which would not only remove substantial quantities of sulfur from the hot metal coming from an acid blast furnace, but which would also bring the sulfur contents down to the low level required in the making of high quality steel and iron.

Principle of the Process

In this paper a new method will be described for desulfurizing hot metal. It has been perfected by

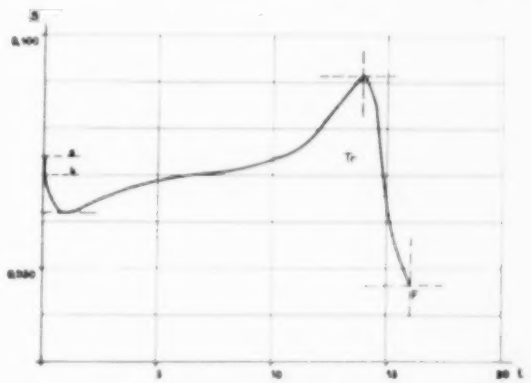


Fig. 1—Sulfur evolution curve during the refining of a basic Bessemer pig iron. S refers to pct of sulfur content in metal, *t*, blowing time, min; *Tr*, end of decarburization; *F*, end of dephosphorization; *a*, sulfur in ladle before pouring; and *b*, sulfur in converter before blowing.

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The Transactions papers appearing in JOURNAL OF METALS *during 1957 will subsequently appear in AIME Transactions Volume 209, and may be permanently referenced to that volume.*

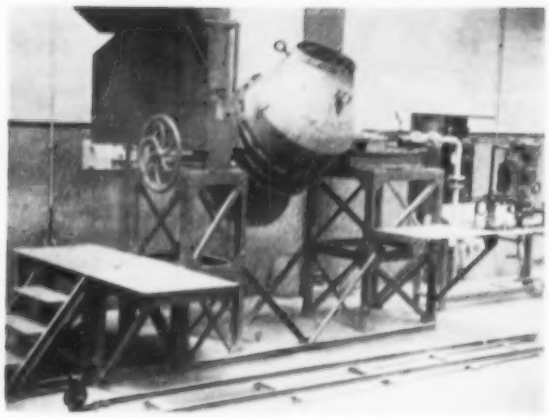

Fig. 2—Photograph of pilot plant 700 lb converter.

the authors after more than 100 tests carried out at both the IRSID pilot plant at Saint-Germain-en-Laye and at the Pont-à-Mousson plant in the east of France. This method is characterized by very efficient conditions of contact between finely ground burnt lime, blown through immersed tuyeres by means of a neutral or reducing gas stream, and the metal bath to be treated. Thus, in a very short time, desulfurizing efficiency will be over 90 pct, and sulfur contents will be very low, less than 0.010 pct if necessary.

The outstanding desulfurizing properties of solid burnt lime are well known in steelmaking. They have already undergone numerous tests of various kinds: the stirring feature of a rotating furnace[1,2] gave satisfactory results in the outstanding experiments of Kalling,[4,5] which led to very low sulfur contents in iron, both on the experimental and on the industrial scale.[5,6] Other methods for obtaining a good mixture of lime and metal have also been tried: induction stirring,[7] gas bubbling,[8,10] and lime coating of coke lumps.[11]

Likewise, suspending lime powder in a gas stream and blowing it into liquid metal is a solution which has long attracted investigators. As this paper treats the lime problem exclusively, mention shall be made only of Wood's famous work on powder injections,[12] which was continued by Baumer, Henderson, and Hulme.[13,14]

Regarding the use of lime, mention shall first be made of Eichholz and Behrendt[3] who, after Oelsen's experimental work,[15] injected a mixture of lime and carbon powder into a stream of compressed air, without obtaining satisfactory results. On the other hand, Sawamura, Okamura, Mori, and Abe[16] used a small graphite crucible in which they blew lime powder into a nitrogen stream with a lance. The only two tests which were made with pure lime did not give very low final sulfur contents—from 0.094 pct before, to 0.050 pct after, treatment.

A paper published in 1952 by the Quebec Iron & Titanium Co. and the Canadian Liquid Air Co.[17] mentions this same method of blowing lime powder into a nitrogen stream with a lance where the operation was carried out in a basic electric furnace. Kalling, before developing the rotating furnace, spoke of having tried blowing lime into a nitrogen stream, but without encouraging results.

One of the authors had already experimented along these lines in a melting shop with an imperfect apparatus, but it was only at the IRSID pilot plant that it became possible for him, on the one hand, to determine that good desulfurization could be obtained by blowing fine powdery products into the metal bath and, on the other hand, to make use of an apparatus to obtain a regular and concentrated suspension of lime powder in a gas stream, and a tilting apparatus similar to a converter.

At the same time, another one of the authors, during a systematic study of the behavior of sulfur at different periods of a basic Bessemer blow, noticed that during the first minute of the blowing, a certain desulfurization (15 to 20 pct) was achieved, owing to the strong stirring of the hot metal with lumps of lime loaded before the blow, Fig. 1. From that, he drew the conclusion that if air were replaced by a non-oxidizing gas and if, instead of loading lumps of lime, lime powder were blown through tuyeres into a converter free from any oxidizing slag, the intimate contact and stirring in such an apparatus would enable a substantial and rapid desulfurization to be obtained.

Equilibrium calculations show that solid lime is a powerful desulfurizing agent for liquid pig iron.

Table I. Types of Pig Irons Treated

	C, Pct	P, Pct	Si, Pct
Normal basic Bessemer pig iron	3.5	1.75	0.1 to 0.6
Semiphosphorus pig iron	3.2 to 4	0.6 to 1	1 to 3
Hematite pig iron	3.2 to 4	0.1	1 to 2.5
Nickel-bearing pig iron	3	0.1	2.5 (Ni = 28 pct)

These calculations are easy for a pig iron containing no silicon and saturated with graphite. The carbon acting as a reducer, the reaction is as follows

$$\underline{CaO}\ (s) + \underline{S} + \underline{C}\ (gr) = \underline{CaS}\ (s) + CO\ (g). \qquad [1]$$

Underlined elements are dissolved in the metal. The s and g refer to solid and gaseous states; gr indicates graphite.

The standard free energy of Eq. 1 is $\Delta F^\circ = 27{,}050 - 27.55\ T$. The reference state for CaO, CaS, and

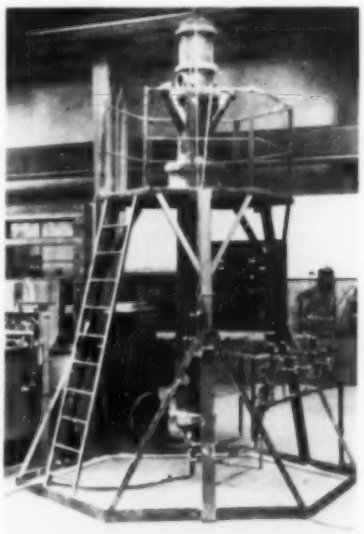

Fig. 3—Photograph of powder-blowing apparatus.

C (*gr*) is the pure substance and, for sulfur in pure liquid iron, is an infinitely dilute solution.

It is then easy to determine the equilibrium constant

$$K_1 = \frac{a_{CaS} \times p_{CO}}{a_{CaO} \times a_S \times a_C}.$$

At about 1300°C, CaO and CaS do not form solid solutions. Therefore, $a_{CaO} = a_{CaS} = 1$. Likewise, the iron being saturated with graphite, $a_C = 1$. If p_{CO} is assumed to equal 1 atm, $K_1 = 1/a_S$; and at 1300°C, $K_1 = 183$.

By taking a sulfur activity coefficient of 5 (graphite-saturated pig iron with a 2 pct P content)

$$[S] = \frac{1}{915} \sim 0.001 \text{ pct.}$$

The equilibrium value of the sulfur content is therefore only 0.001 pct. The p_{CO} is assumed to equal 1 atm. For the process developed in this paper, the blowing of nitrogen leads to $p_{N_2} + p_{CO} = 1$ atm, resulting in a lower equilibrium value for the final sulfur.

A recent paper written by Sawamura[18] develops the thermodynamics of the desulfurization of pig iron free from silicon by means of lime and calcium carbide.

From a practical standpoint, however, pig iron always contains silicon, so at normal treatment temperatures, Eq. 1 is replaced by Eq. 2

$$2\,CaO\ (s) + 2\,\underline{S} + \underline{Si} = 2\,CaS\ (s) + SiO_2\ (s). \quad [2]$$

Eketorp[19] proved recently that, by assuming the formation of pure dicalcium silicate and the insolubility of CaO, CaS, and SiO_2, 2 CaO, the equilibrium value of the sulfur content at 1300°C is 2.5 10^{-5} pct

Table II. Lime Analysis

CaO, Pct	SiO_2, Pct	Fe_2O_3 + Al_2O_3, Pct	CO_2 + H_2O, Pct	S, Pct
93	1.2	1.3	3	0.07

for a pig iron of the following composition: 3.4 pct C, 0.3 pct Si, 0.8 pct Mn, and 1.8 pct P.

Thus, thermodynamic calculations for the desulfurizing of liquid pig iron with lime lead to extremely low residual sulfur contents and, although many investigators have tried blowing lime powder and nitrogen, they have not succeeded in getting systematically low residual sulfur contents. The authors have tried to desulfurize by blowing lime powder into a neutral gas, but with a different technique, based upon the excellent conditions of contact and stirring achieved by immersed tuyeres.

Experimental Work

Apparatus—The small 700 lb converter used in the first series of tests at the pilot plant of Saint-Germain-en-Laye is shown in Fig. 2.

The lime powder, drawn along in a stream of nitrogen, is blown through the metal bath by means of small tuyeres placed in the bottom of the converter, which is lined with a mixture of dolomite and tar.

Fig. 3 shows the powder blowing apparatus* whose main feature is the lime concentration in the gas stream of up to 2.4 lb per cu ft of blown nitrogen.

* Patent registered.

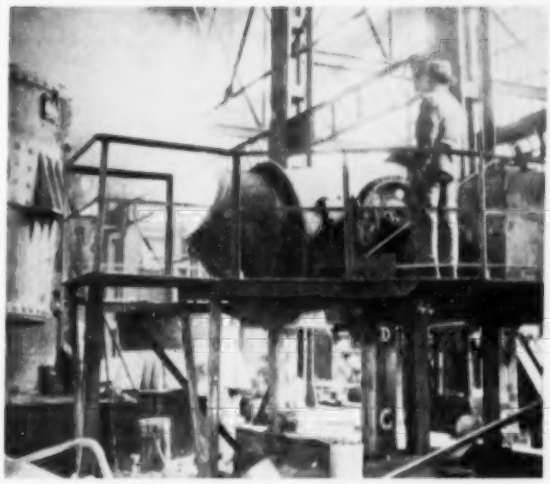

Fig. 4—Photograph of experimental 6,000 lb converter.

Fig. 4 represents the experimental 6,000 lb converter used at the Pont-à-Mousson plant of the Société des Fonderies de Pont-à-Mousson, where the second series of tests was undertaken. The hot metal was brought along in 30,000 lb ladles, but the experimental technique was the same as the one followed at the Saint-Germain-en-Laye pilot plant, with the 700 lb converter.

It is to be noted that this desulfurization process can be carried out in vessels other than a converter. At present, a special ladle with a set of tuyeres is being tested. It has the great advantage of being able to be used for desulfurizing and transporting hot metal at the same time.

Liquid Pig Iron—At the time this paper was written, over 100 tests had already been carried out on pig irons of several different compositions, shown in Table I.

As far as the sulfur contents of the pig irons before treatment are concerned, they varied within a range of 0.015 to 0.300 pct. More than half these pig irons, however, had sulfur contents before treatment of between 0.060 and 0.120 pct.

Table III. Desulfurization of 1 Pct P Liquid Pig Iron

Sample No.	Blowing Time, Min	Lime Blown, Lb	S, Pct	C, Pct	Si, Pct	Mn, Pct	Desulfurization Efficiency, Pct*
P 10$_1$	0	0	0.095	3.3	3.0	0.465	—
P 10$_2$	1	37	0.047	3.3	3.0	0.455	50
P 10$_3$	2	75	0.017	3.1	2.9	0.455	82
P 10$_4$	3	112	0.009	3.1	2.9	0.450	90

* Desulfurization efficiency $= \frac{S_{start} - S_{final}}{S_{start}} \times 100$

Lime—The burnt lime used for all these tests was a product of industrial quality, and of low cost. It was supplied by a French steel plant which has gas heated furnaces, thus enabling a good quality lime to be obtained. Lime analysis is shown in Table II.

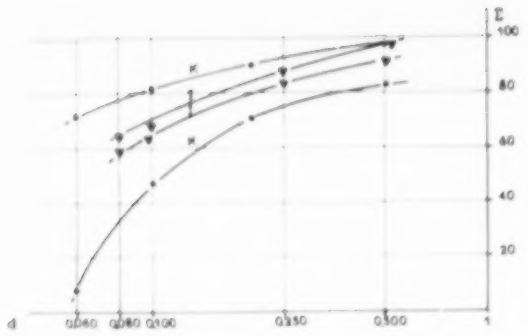

Fig. 5—Lime powder grain size. *I* refers to IRSID's present tests, *K*, Kalling's data, *d*, powder grain size, mm; and *ε*, pct under given size.

It is to be noted that unburned parts and siliceous impurities can have a harmful effect on the efficiency of desulfurization, but the sulfur content of lime at start is of no importance (equilibrium corresponding to CaS).

The grain size of the lime powder used is given by the two curves shown in Fig. 5, and is compared with the grain size of the lime powder used by Kalling for his tests on the 6,600 lb rotating furnace.

Nitrogen—Only a few tests at the very beginning were carried out with specially purified nitrogen. Ordinary nitrogen, containing less than 0.5 pct O, was used in most tests.

Description of a Desulfurization Treatment—Desulfurizing, either in the 700 lb or the 6,000 lb apparatus, is simple and short. Liquid pig iron is poured into the converter in its horizontal position and, after a sample of metal has been taken, nitrogen and lime are blown in. As soon as a white cloud

Table IV. Desulfurization of 0.7 Pct P Pig Iron

Sample No.	Blowing Time, Min	Lime Blown, Lb	S, Pct	C, Pct	Si, Pct	Desulfurization Efficiency, Pct
P 14,	0	0	0.092	3.5	2.6	—
P 14,	1½	55	0.025	3.4	2.6	73
P 14,	3	110	<0.003	3.4	2.5	>96
P 14,	4½	168	<0.003	3.5	2.6	>96

appears at the nose of the converter, it is tilted into its vertical position for the whole length of the blow, which lasts about 3 min. At the end of this period, the converter is tilted down into its horizontal position and the lime and nitrogen supplies are stopped. After sampling the metal bath, the liquid pig iron is poured into a ladle, and retained lime runs out of the converter when it has been completely tilted down.

Results

In order to study this desulfurization method better, many tests were carried out with intermediate tiltings and corresponding metal sampling, so that sulfur evolution curves could be drawn. In most cases, the lime and nitrogen supplies were kept constant during the whole test, and many preliminary experiments have shown that, under these conditions, the lime flow remained quite regular.

a) Table III summarizes the results obtained with 5,500 lb of semiphosphorus liquid pig iron (1 pct P) treated in the apparatus set up at the Pont-a-Mousson plant and previously shown, Fig. 4.

Blowing time was divided into three equal periods of 1 min each, and the corresponding sulfur evolution curve is given in Fig. 6.

This test shows that: starting from a value of 0.095 pct, the sulfur content is finally reduced to 0.009 pct, representing a desulfurization efficiency of 90 pct; this important desulfurization is obtained very quickly in a total blowing time of only 3 min; and carbon, silicon, and manganese contents show a slight decrease from the beginning to the end of the blow.

b) The steep slope of the desulfurization curve results from the excellent conditions of contact between the metal bath and the desulfurizing agent, which is obtained through this way of treating pig iron. The steep slope was found in most of the tests made.

Table IV gives an analysis of samples taken every 1½ min during a test carried out with a mass of 5,500 lb of semiphosphorus pig iron (P = 0.70 pct).

Fig. 7 shows desulfurization efficiency as well as the rapidity of this operation. Two min after the start, desulfurization has already attained 90 pct, while the lime consumption is less than 2 pct of the weight of treated metal; and in less than 3 min, the sulfur content is brought down to less than 0.003 pct, which is the lowest value obtainable with the method of chemical analysis used (combustion method), and which means a desulfurization efficiency exceeding 96 pct. There is no way of telling

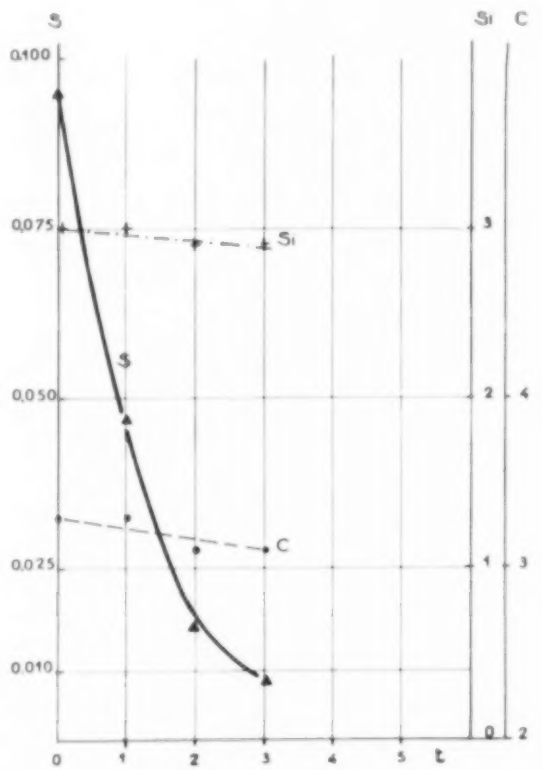

Fig. 6—Sulfur evolution curve, Heat P 10, 5,500 lb of pig iron. S refers to pct of sulfur content; *Si*, pct of silicon content; C, pct of carbon content; and *t*, blowing time, min.

whether further lime blowing lowers sulfur contents.

c) It is possible to achieve greater desulfurization speed by increasing the lime flow rate. Thus, the test given in Table V represents a charge of 5,100 lb of pig iron (1 pct P) treated with 117 lb of lime powder. The sulfur content dropped from a value of 0.088 pct at the beginning to 0.005 pct after only 1½ min, which means a desulfurization efficiency of 94 pct.

d) The first series of desulfurization experiments carried out with the small 700 lb converter, Fig. 2, proved that this new process could be very efficient and gave encouragement for the undertaking of tests on a larger scale. However, these experiments on a mass of metal weighing only 700 lb met with serious difficulties because too few tests, one or two, seldom three, were made per day; and also because the lining needed preheating between each test with a gas burner, which oxidized the metal left on the lining from previous tests. These high thermal losses and the presence of an oxidized slag are unfavorable for desulfurization efficiency.

Fig. 8 represents the desulfurization efficiency obtained with 32 tests on basic Bessemer pig iron (1.7 to 1.8 pct P) containing from 0.030 up to 0.100 pct S before treatment in the 700 lb converter.

The points on Fig. 8 show a marked tendency toward the horizontal assymptote corresponding to a 100 pct desulfurization, but are greatly scattered; and the lime consumption is high. This is due to the formation of iron silicates owing to the oxidizing preheating of the lining, all the more dangerous as

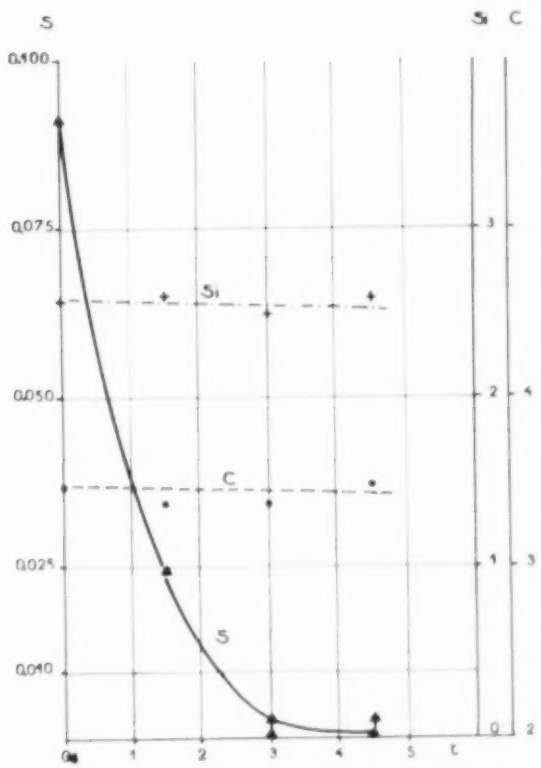

Fig. 7—Sulfur evolution curve, Heat P 14; 5,500 lb of pig iron. S refers to pct of sulfur content; Si, pct of silicon content; C, pct of carbon content; and t, blowing time, min.

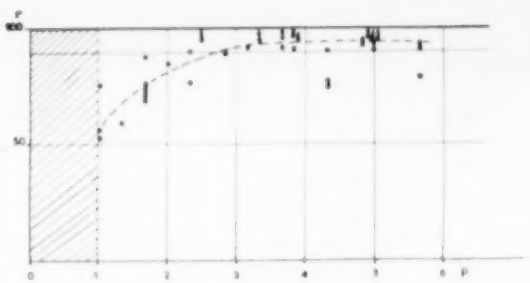

Fig. 8—Desulfurization obtained with the 700 lb apparatus with basic Bessemer pig iron. Lining oxidized by preheating. Sulfur content at the beginning is between 0.030 and 0.100 pct. The *r* refers to pct of desulfurization efficiency, the *p*, lime consumption (wt pct of metal bath).

the ratio between metal weight and lining surface is more important for a small mass of metal.

e) With this small scale converter, the authors tried adding various elements to the lime, in particular carbon, aluminum, magnesium, calcium carbide, and calcium cyanamid. The addition of carbon (finely crushed charcoal) did not make much of an improvement. Fig. 9 shows the results obtained with 660 lb of basic Bessemer pig iron treated with 25 lb lime powder mixed with 25 pct of its weight of crushed charcoal. Results appear to be no different from those obtained without charcoal in this small converter. A marked decrease in the silicon content (from 0.66 to 0.40 pct) resulted from the oxidized lining.

f) The use of this small 700 lb converter has, however, made it possible to prove the favorable effect of the small addition of a powerful reducing agent, such as aluminum.

By adding only 2 pct aluminum powder to the lime, it was possible to attain extremely low sulfur contents, less than 0.003 pct, which is the lowest obtainable with the combustion method used for

Table V. Desulfurization with Increased Lime Flow Rate

Sample No.	Blowing Time, Min	Lime Blown, Lb	S, Pct	C, Pct	Si, Pct	Mn, Pct	Desulfurization Efficiency, Pct
P 21$_1$	0	0	0.088	3.2	2.9	0.42	—
P 21$_2$	1½	117	0.005	3.1	2.8	0.42	94

sulfur analysis. Small arrows have been put next to corresponding points on the graph of Fig. 8 in order to show that the desulfurization efficiency is close to 100 pct. A sulfur evolution curve with aluminum addition to lime is given in Fig. 10.

The example given in Fig. 10 is also quite significant. The 660 lb basic Bessemer pig iron with 1.8 pct P and a very high sulfur content (0.300 pct) was treated with 24 lb of lime containing 2 pct of its weight of aluminum powder.

Table VI summarizes the data obtained, and shows the extremely sharp decrease in the sulfur content, dropping in 4½ min from 0.300 to 0.004 pct. Desulfurization efficiency here reaches 99 pct.

This desulfurizing method therefore seems to be particularly convenient for the quick treatment of

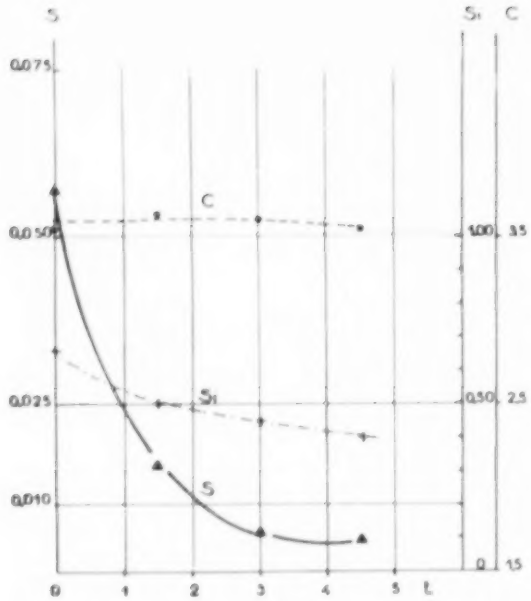

Fig. 9—Sulfur evolution curve, Heat Bb 194; charcoal addition, 660 lb of pig iron. S refers to pct of sulfur content; Si, pct of silicon content; C, pct of carbon content; and t, blowing time, min.

high sulfur pig irons, such as those produced in blast furnaces operated with slags of low basicity ratio.

It must be pointed out that for all these tests, metal sampling was done immediately after tilting down the converter.

Table VI. Desulfurization with Aluminum Powder Additions

Sample No.	Blowing Time, Min	Lime Blown, Lb	S, Pct	C, Pct	Si, Pct	Mn, Pct	Desulfurization Efficiency, Pct
Bc 202	0	0	0.300	3.6	0.47	0.35	—
Bc 202	1½	7.5	0.056	3.5	0.36	0.34	81
Bc 202	3	16.5	0.015	3.5	0.31	0.34	95
Bc 202	4½	24	0.004	3.5	0.27	0.33	99

The extremely low sulfur contents finally attained seem to indicate that the sulfurized particles rise up through the metal bath very quickly. In order to check that point, during several different tests the analysis of a metal sample taken just after tilting down was compared with the analysis of another sample taken after a holding time of several minutes. An example of the results obtained with a charge of 6,200 lb of hematite pig iron treated with lime powder and with a holding period of 3 min after final tilting down is given in Table VII and Fig. 11.

Other tests carried out along these lines point to a similar conclusion. Waiting after blowing has stopped has no apparent influence upon the sulfur content of the metal sample. This point is an advantage of the present method compared with other methods, where it is necessary to hold the bath several minutes while the desulfurizing particles rise up through the metal.

The lime slag can have different colors according to conditions. An oxidizing preheating of the small 700 lb converter gives a final dark lime, a substantial part of which is sintered into balls having a diameter of up to 1 in. Where it was possible to avoid the presence of oxidizing slag or of fairly substantial amounts of foreign slag coming from the large 30,000 lb ladles, a light colored lime, pulverulent and barely sintered, was obtained; desulfurizing then attained a very high percentage.

As with the Kalling process, the lime obtained contains metallic shots the size of which varies up to ¼ in., but they can easily be removed by screening and magnetic separation.

Thermal losses on the 700 lb and even 6,000 lb tests cannot be compared with those encountered with a mass of metal of 50,000 lb or more. The technique at present consists of treating pig iron in a special ladle used for the transportation of the metal, in order to avoid thermal losses due to the use of a supplementary apparatus.

The thermal loss caused by the nitrogen (or other gases) blown through the metal bath could seem to be a disturbing factor, and it is necessary to give a maximum value to the resulting loss of heat.

One of the main features of the powder blowing apparatus used for all these tests is, as already said, the high lime concentration achieved in the gas stream. Taking a consumption of lime of 2 pct of the weight of metal to attain a desulfurization efficiency of 90 pct with the 6,000 lb apparatus, the nitrogen consumption comes to 18 cu ft per metric ton of pig iron treated. If it is assumed that temperature of nitrogen increases from 20° to 1300°C,

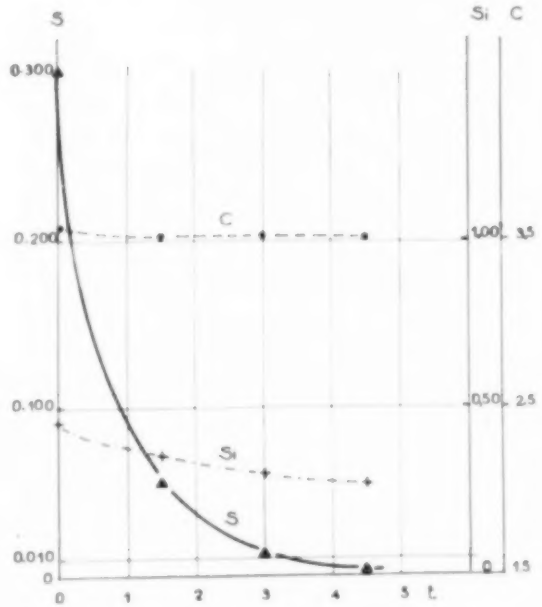

Fig. 10—Sulfur evolution curve, Heat Bc 202; 660 lb of pig iron. S refers to pct of sulfur content; Si, pct of silicon content; C, pct of carbon content; and t, blowing time, min.

which is the temperature of the metal bath, the following maximum value for the thermal loss due to the nitrogen blown through the metal bath is obtained: $\Delta t = 1.3$°C or 2.3°F.

It thus becomes apparent that the temperature drop due to the nitrogen itself is very small and can be neglected.

A similar calculation shows that the temperature drop due to a weight of lime of 2 pct of the metal bath is about 30°C or 54°F.

By taking into account the heat evolved in the exothermic desulfurization Eq. 2, and the heat coming from oxidation of silicon due to oxygen traces, a gain of about 15°C or 27°F is obtained. The net loss is therefore of the order of 15°C or 27°F.

Conclusions

This paper describes a new method of desulfurizing liquid pig iron. A very intimate contact between the metal bath and the lime powder blown in during the operation through immersed tuyeres, together with the precautions taken to avoid the presence of oxidized or foreign slags, makes an important and rapid desulfurization possible.

This method appears to be efficient, as a sulfur content of less than 0.003 pct can easily be achieved, and high sulfur pig iron (with, for example, 0.300 pct S) can be thoroughly desulfurized.

The method is very quick, the time of treatment varying from 3 to 4 min. Sulfur evolution curves show a sharp drop at the beginning of the blow. It is unnecessary to have a holding period to allow sulfurized particles to rise up through the metal.

Experiments have shown that on a mass of 6,000 lb of metal, a lime consumption of 2 pct of the weight of metal makes sulfur content drop from 0.100 pct to less than 0.010 pct. Lime is cheap and its high concentration in the gas stream leads to a very small thermal loss resulting from the blowing of the gas.

This method can, therefore, be applied to all the different problems of pig iron desulfurization encountered either in foundries or in integrated steel plants, and especially in those operating acid blast furnaces.

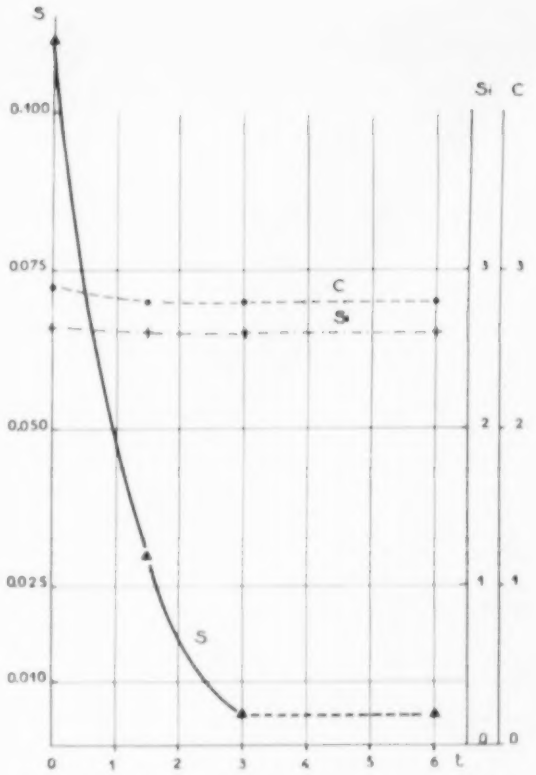

Fig. 11—Sulfur evolution curve, showing no influence from the holding period. Heat P 46; 6,200 lb of pig iron. S refers to pct of sulfur content; Si, pct of silicon content; C, pct of carbon content; and t, time, min. Blowing time was 3 min and holding time was 3 min.

Table VII. Desulfurization of Hematite Pig Iron

Sample No.	Blowing Time, Min	Lime Blown, Lb	S, Pct	C, Pct	Si, Pct	Mn, Pct	Desulfurization Efficiency, Pct
P 46$_1$	0	0	0.112	2.9	2.65	0.76	—
P 46$_2$	1½	60	0.030	2.8	2.60	0.75	73
P 46$_3$	3	119	0.005	2.8	2.60	0.75	95
P 46$_4$	Holding period of 3 min after final tilting down		0.005	2.8	2.60	0.75	95

Acknowledgments

This research work would not have reached success had it not been for the skillful and unfailing assistance of E. Vitout, head of the IRSID pilot plant, who, from the very beginning of the tests, took care of an important part of the technological details. Thanks are due to R. Planiol for his kind cooperation in the powder blowing field. Finally, the authors wish to express their deep gratitude to the Société des Fonderies de Pont-à-Mousson for the close cooperation and encouraging support which they were given at all times and which enabled the 6,000 lb tests to be carried out quickly and efficiently.

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Synthesis of Some Ferrites

by Horst Kedesdy and Arthur Tauber

FERRITES are sintered metallic oxides of the spinel structure type[1] and belong to the class of soft ferromagnetic materials. Similar to a ceramic, they can be formed and fired to a dense body, exhibiting a high electrical volume resistivity ranging from 10^2 to 10^7 ohm-cm as compared with 10^{-6} ohm-cm for some of the metallic magnetic materials. This high resistivity, with resulting low eddy current losses, finds special application at high frequencies. The dispersive susceptibility of ferrites at microwave frequencies has also led to many applications in this field. Ferrites are used in low frequency applications where high resistivity with high permeability is desirable. During the last few years ferrites exhibiting rectangular hysteresis loops have been developed for computer and magnetic memory systems.

The general formula for ferrites is $MeFe_2O_4$ where Me is a divalent metal ion such as Ni, Zn, Mg, Mn, Cu, Cd, and Fe. Only two of these ferrites are nonferromagnetic, namely, those with Zn and Cd. Solid solutions can be formed between different ferrites, and it is of interest to note that solid solutions of a ferromagnetic ferrite with a nonferromagnetic ferrite yield much better magnetic materials than the basic ferrite body. In general, it can be said that the solid solution formation between ferrites has widened the field of ferrite synthesis and has led to methods of preparing materials with a large variety of magnetic properties.

During the last two decades the synthesis of ferromagnetic oxides has been the object of extensive research, but commercial production has been started only within the last ten years. Along with more fundamental studies, there remains the never-ending task of developing ways to realize the optimum characteristics of materials in large-scale production. Ordinarily, to produce a ferrite material it is necessary for the constituent oxides to be mixed intimately, pressed, and then fired at temperatures above 1000°C.

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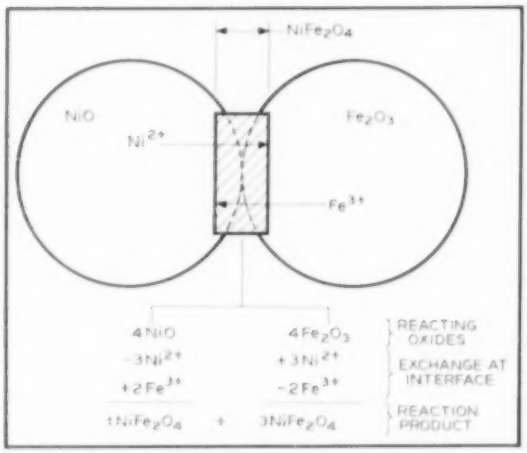


Fig. 1—Reaction mechanism for Ni-ferrite formation. (After C. Wagner.[2])

Ferrite Synthesis: Formation of a basic ferrite by solid state reaction from Fe_2O_3 and a monoxide such as NiO, under normal atmospheric conditions, is governed by a progressive diffusion of cations between adjacent particles of the constituents. Firing temperature, furnace atmosphere, and cooling can vary the magnetic properties, however. If, for example, a dioxide, a sesquioxide, or an oxide of the Me_3O_4 type is substituted for the monoxide, the reaction mechanism becomes more complex and extremely dependent on atmospheric conditions and firing cycles. For this reason reproduction often

Table I. Spectrochemical Analysis of the Constituent Oxides and Fired Toroid Cores*

Element Analyzed for	Fe_2O_3	$MnCO_3$	NiO	$NiFe_2O_4$	$Ni_{.5}Zn_{.5}Fe_2O_4$	$MnFe_2O_4$
Si	0.01	<0.01	0.06	0.1	0.1	0.01
Al	0.01	0.01	0.005	0.02	0.002	<0.01
Fe	Major	<0.01	Not detected	Major	Major	Major
Mg	Not detected	0.01	Not detected	Not detected	Not detected	<0.01
Ca	Not detected	<0.01	Not detected	Not detected	Not detected	0.01
Pb	Not detected	<0.02	Not detected	Not detected	Not detected	Not detected
Sn	Not detected	Not detected	Not detected	Not detected	Not detected	Not detected
Ti	<0.01	Not detected	Not detected	Not detected	Not detected	0.01
V	<0.01	Not detected	Not detected	Not detected	Not detected	Not detected
Cr	<0.01	Not detected	<0.001	Not detected	Not detected	Not detected
Mn	0.01	Major	0.01	<0.01	<0.01	Major
Cu	<0.01	Not detected	0.002	0.003	0.003	<0.01
Ni	0.01	Not detected	Major	Major	Major	0.01
Zn	Not detected	Not detected	Not detected	Major	Major	Not detected

* Results are in weight percent.

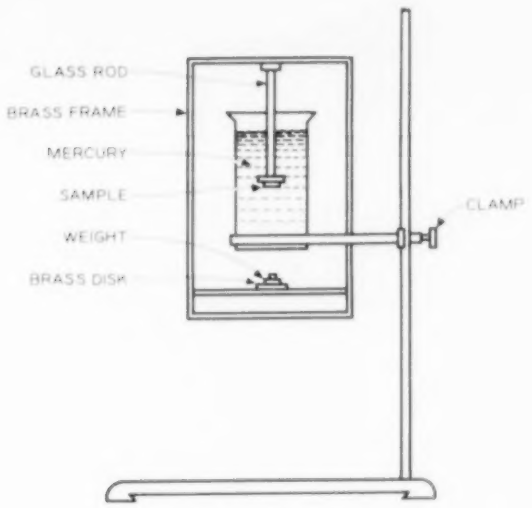


Fig. 2—Bulk density apparatus.

fails even in cores from the same batch material, with the same magnetic properties. Synthesis of a ferromagnetic oxide of final magnetic properties consists not only of a completion of the solid state reaction between the constituent oxides to form the spinel structure, but also in the densification of material, diffusion of the cations to form a homogeneous body, and grain growth.

This article discusses results of systematic investigations of the formation of a basic ferrite, such as Ni ferrite; a mixed ferrite, such as NiZn-ferrite; and a ferrite involving a complex formation process, such as Mn-ferrite. Trends in magnetic characteristics are related to change in firing cycle and furnace atmosphere.

Specimen Preparation and Testing Procedures: For synthesis of Ni- and NiZn-ferrite, constituent oxide mixtures consisted of Fe_2O_3 with NiO and with NiO + ZnO (1:1); for the Mn-ferrite synthesis an oxide mixture of Fe_2O_3 and Mn_2O_3 was chosen.

Single-phase Baker-analyzed reagent NiO, Fisher ZnO, and Fe_2O_3 of C.P. grade were used in preparing the samples. Mn_2O_3 was prepared from Fisher C.P. grade $MnCO_3$ by heating in air at 1000°C for 1 hr and air quenching to room temperature. The sample was then reground, reheated for another hour at the same temperature, and then quenched to room temperature. Particle size, as determined by electron microscopy, was about 0.01μ for Fe_2O_3, 0.1μ for NiO, and 1μ for Mn_2O_3.

Pellets ½-in. OD and ¼-in. thick, pressed at 25,000 psi, were used for the solid state reaction studies. The pellets were prepared from the powdered oxides, which were dried overnight at 110°C. The exact weights of oxides were measured, mixed, and ground in the dry state in a boron carbide mortar for about 3 hr. Spectrochemical analysis indicated no contamination from the mortar.

For the magnetic studies toroids were selected, prepared by mixing and grinding carefully weighed constituent oxides. The dry oxides were ground in a boron carbide mortar in 3 hr. Subsequently each mixture was pressed into pellets at 25,000 psi, calcined in static air at 950°C for 5 hr in a globar furnace, and cooled by air quenching. The calcined

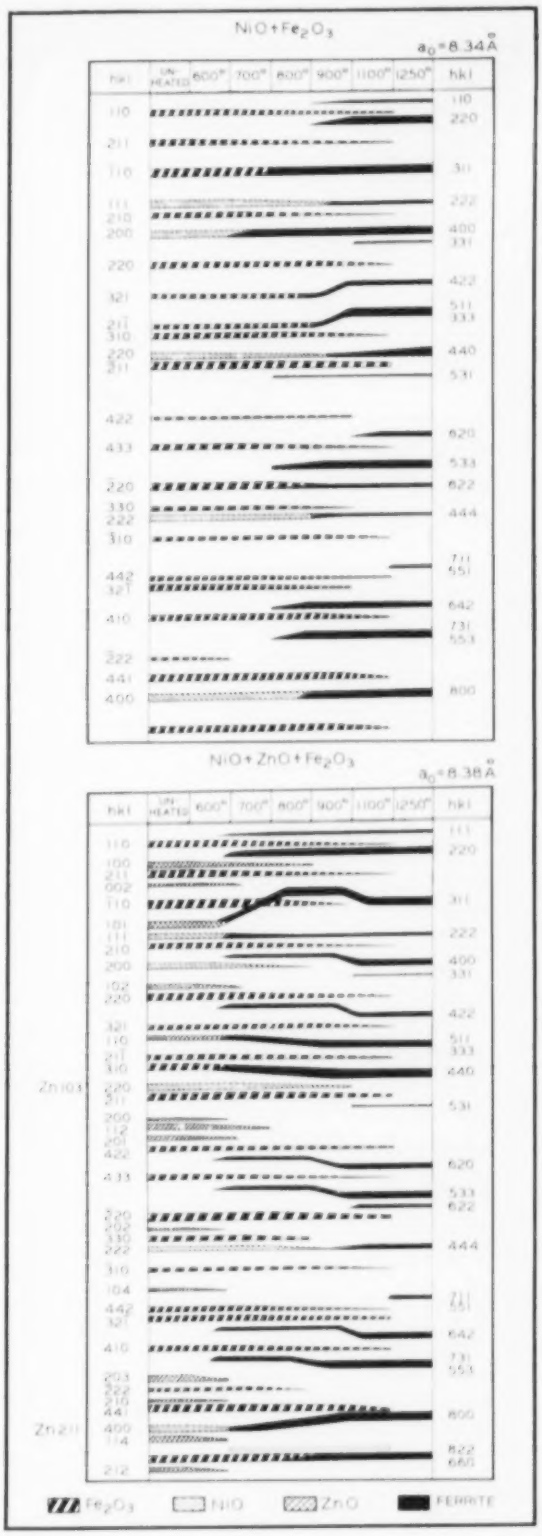


Fig. 3—Ferrite formation from X-ray diffraction data.

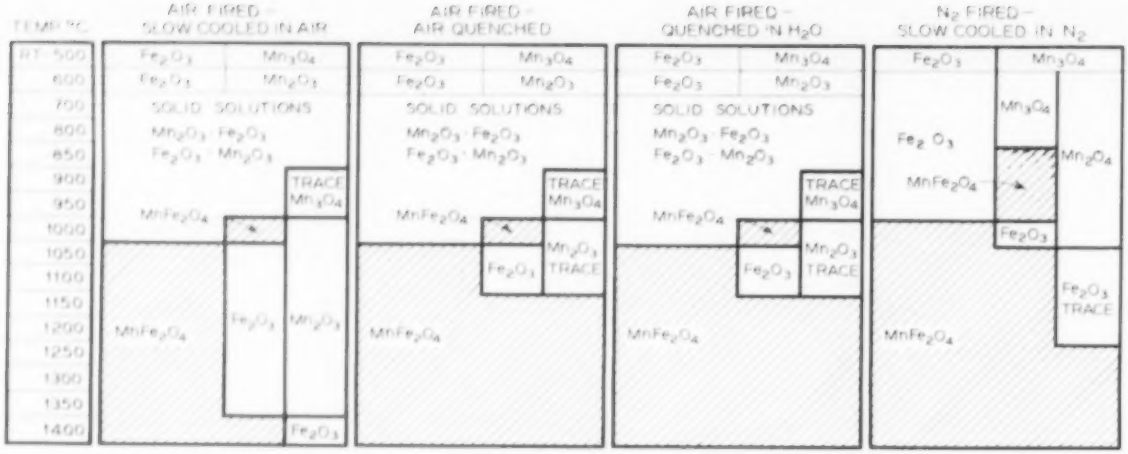


Fig. 4—The Mn ferrite formation under different firing conditions. Wide columns indicate major phase and narrow columns minor phase.

product was broken up in a steel mortar and transferred to a motorized mullite mortar, where it was ground with water for 2 hr. The resulting cake was dried out at 110°C and the material passed through a series of sieves; the last increment contained particles that had passed through a No. 150 Standard U. S. sieve.

For every 50 g of sample, 2 cu cm of a 4 pct aqueous solution of DuPont Polyvinyl alcohol were added as a binder. The binder was volatilized as the toroids were heated slowly during the appropriate firing cycle. Spectrochemical analyses of these toroids are given in Table I. All pellets and toroids were fired in a Baker E-2 platinum wound resistance furnace. Both pellets and toroids were fired for 5 hr, at the final temperature, with the following firing cycles:

A. Heated and Slow-Cooled in Air: Samples heated in this cycle were brought to the final temperature at about 150°C per hr. After the samples were soaked 5 hr, the furnace was turned off and the cooling followed a parabolic curve; room temperature was reached in 2 to 3 hr, depending on the soak temperature.

B. Heated in Air and Quenched in Air: The heating cycle was the same as in *A*. Cooling, however, was accomplished by removing the sample from the furnace at its soak temperature, then permitting it to cool to room temperature on a ceramic block; cooling time was no longer than 10 min.

C. Heated in Nitrogen and Slow-Cooled in Nitrogen: The heating cycle was the same as in *A* and *B* except that a nitrogen atmosphere, at a pressure slightly above atmospheric and at a flow rate of 0.5 liters per min, was maintained throughout the entire firing cycle. After 5 hr of firing the furnace was turned off and the sample left to cool. Here, a nitrogen stream was maintained until room temperature was reached, speeding the cooling process in this part of the cycle.

D. Heated in Air and Quenched in Water: This additional firing cycle, used in the study of Mn-ferrite, applies to formation studies only. The heating cycle was identical to the cycle for samples fired previously. The sample was then removed quickly from the furnace while it was at soak temperature and dropped into distilled water, cooling to room temperature within 8 sec. Firing temperatures ranged from 600° to 1400°C for the solid state reactions and from 1000° to 1450°C for the magnetic studies.

X-Ray Diffraction Studies: X-ray diffraction was used to study the solid state reaction. FeK-radiation, filtered through manganese oxide, was used throughout. Both Debye-Scherrer powder film patterns and diffractometer traces were prepared. The film patterns were made by grinding to a powder the sintered ceramic material from the central portions of pellets or toroids. Diffractometer traces were prepared from powdered samples, as well as from unmodified and polished surfaces of the sintered ceramics.

Magnetic Measurements: The hysteresis loop traces were obtained with an automatic recording flux meter,[5] which produced a trace of the curves on standard rectangular coordinate paper.

All toroids were wound with 3000 primary and 30 secondary windings. The primary winding is used to generate the magnetizing force by energizing it with a controlled direct current; *H*, the

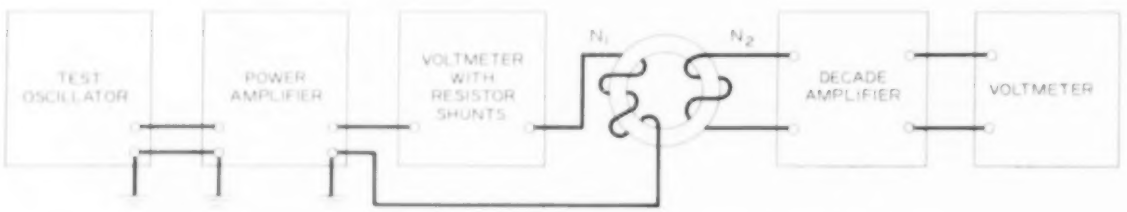


Fig. 5—Schematic block diagram for determination of initial permeability of toroidal ferrite cores.

magnetic strength in oersted, is proportional to I, the magnetizing current. The secondary winding is connected with the integrating elements of the flux meter. The meter converts the change in flux, linking the search coil, to variations in current proportional to the flux density, B. The scales of the two mechanisms of the recorder are adjusted by the two currents fed to it through separate networks. The B element mechanism drives the pen proportionately to B, while the H mechanism drives the paper drum proportionately to H. The B-H loop is traced by constantly increasing the magnetic current from zero to a positive value, immediately followed by a cyclic reversal of the same value. All measurements were made at a maximum field strength (H) of 25 oersteds. Initial permeability (μ_i) was determined with a conventional bridge circuit at 1 kc. Measurements for initial d-c permeability were made on the same toroids used for hysteresis loop tracing without a change of windings. An oscillator was used to drive the primary of the toroids (Fig. 3). The primary magnetizing current and voltage and the voltage in the secondary winding were measured with vacuum tube voltmeters. An average value for initial permeability was obtained for each core from nine individual measurements made close to zero field H (0-25 milli oersteds). Initial permeability can be calculated from

$$\mu_i = \frac{B}{H}$$

where

$$B = \frac{22.5 \cdot E_2}{A \cdot N_2 \cdot f}$$

$$H = \frac{0.4 \cdot \sqrt{2}\, I_1 \cdot N_1}{d_m}$$

E_2 = voltage in millivolts across secondary winding.
A = cross sectional area of core in cm².
N_1 = number of primary turns.
N_2 = number of secondary turns.
f = operating frequency (1 kc).
I_1 = primary current in amperes.
d_m = mean diameter of core in centimeter.

Bulk Density Measurements: Bulk density measurements were made with a device based on Archimedes' principle—a brass wire frame of about 4 x 6 in. shown in Fig. 2. A small nut is soldered in the center of the crosspiece and into this is screwed a glass rod 2 in. long that terminates in a flattened disk. Soldered to the crosspiece on the bottom of the device is a brass disk that holds the weights used in the measuring process. The whole device is suspended over a small beaker of mercury. The sample is floated on the surface and the disk of the rod rests directly on it. The weights are placed on the brass disk until the mercury meniscus is aligned with a predetermined zero point on the glass rod. The density of the sample is given by

$$d_s = d_{Hg} \cdot \frac{W_s}{W_s + W_s'}$$

where

d_{Hg} = density of mercury in g per cm³.
W_s = weight of sample in air, g.
W_s' = weight of sample in mercury, g.

Data for densities and weights must be determined at the same temperature. In these investigations measurements were performed at 26°C.

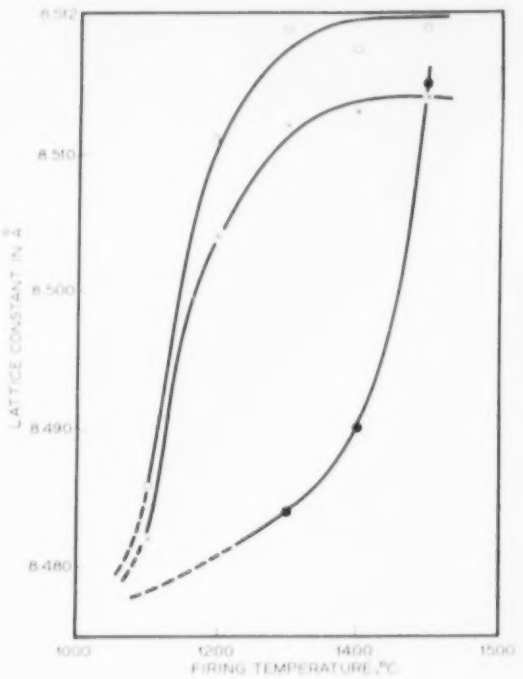


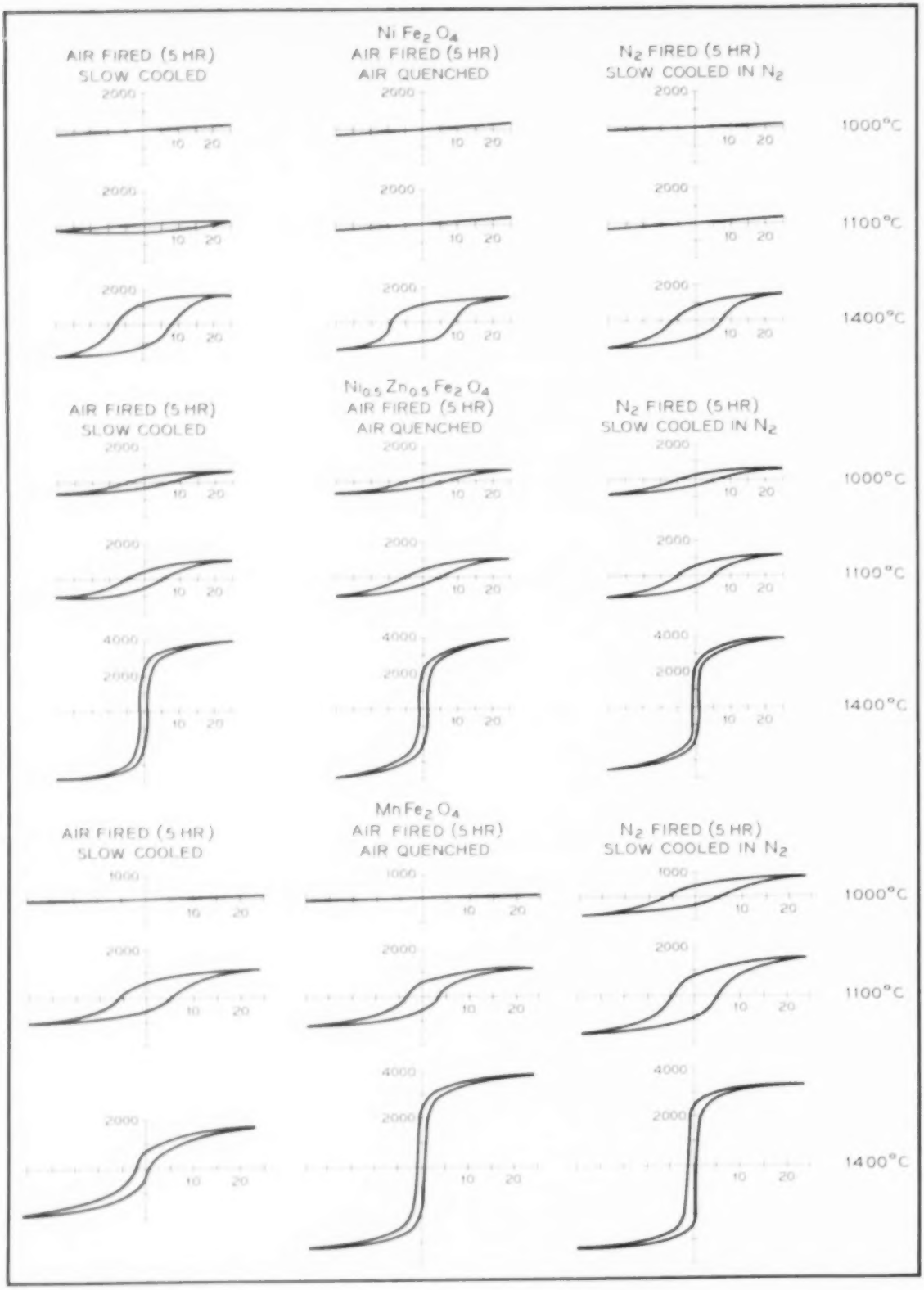
Fig. 6—Lattice constant of Mn-ferrite vs firing temperature. Crosses indicate air firing and air quenching to RT; solid circles indicate air firing and slow cooling in furnace to RT; and open circles indicate firing in a gaseous N_2 atmosphere with slow cooling in N_2 to RT.

Experimental Results

Formation of Solid State Reaction: Ferrite formation, as determined by X-ray diffraction measurements, begins between 650° and 700°C for both Ni-ferrite and NiZn-ferrite; for the Mn-ferrite, temperatures between 850° and 1000°C are required, depending on furnace atmosphere. The reaction mechanism for the formation of Ni- or NiZn-ferrites from their constituent oxides can be visualized as a Wagner type of diffusion[4] at the particle interface (Fig. 1). The reaction leading to the formation of Ni-ferrite can be represented, for example, by:

$$NiO + Fe_2O_3 \rightarrow NiFe_2O_4$$

Fig. 3 is a graphical representation[4] based on X-ray diffraction data, obtained from powdered ceramic pellets, of the formation in air of Ni- and NiZn-ferrite. Diffraction lines of the unreacted oxide mixture are plotted on the left side of each diagram in such a way that from the top to the bottom the diffraction angle increases. Any change in position or intensity of diffraction lines, at increasing firing temperature, is easily noted by following the lines across the diagram. The right hand side of the diagram shows the completed ferrite diffraction pattern (black lines). Pronounced shifts of the ferrite lines are seen in the first stage of formation, indicating crystal lattice distortion of the newly formed ferrite phase. This distortion vanishes as higher firing temperatures are reached. Accurate lattice constant measurements have shown that for bodies quenched from 1000° to 1200°C there is first an increase in lattice constant, followed by a slight decrease. The total change never exceeds 0.005A. A single-phase material is observed after firing at 1250° or higher.



Figs. 7, 8, and 9—Hysteresis loops of Ni, Ni-Zn, and Mn ferrites prepared under different conditions. Abscissa scale is in oersteds and ordinate scale in gauss.

Table II. Chemical Reactions Governing the Formation of $MnFe_2O_4$ from $Mn_3O_4 + Fe_2O_3$ (1:3 Mols) in Air and Nitrogen

Heating in Air Atmosphere		
1. Initial mixture:		(Mn_3O_4 + 3 Fe_2O_3)
2. At 600°C (oxidation of Mn_3O_4):	$Mn_3O_4 + \frac{1}{4}O_2 \rightarrow 1.5\ Mn_2O_3$	(1.5 Mn_2O_3 + 3 Fe_2O_3)
3. At 950°C (reduction of Mn_2O_3):	$1.5\ Mn_2O_3 \rightarrow Mn_3O_4 + \frac{1}{4}O_2$	(Mn_3O_4 + 3 Fe_2O_3)
4. At 1000°C (ferrite formation and reduction):	$Mn_3O_4 + 3\ Fe_2O_3 \rightarrow 3\ MnFe_2O_4 + \frac{1}{2}O_2$	(3 $MnFe_2O_4$)
Heating in Nitrogen Atmosphere		
1. Initial mixture:		(Mn_3O_4 + 3 Fe_2O_3)
2. At 850°C (ferrite formation and reduction):	$Mn_3O_4 + 3\ Fe_2O_3 \rightarrow 3\ MnFe_2O_4 + \frac{1}{2}O_2$	(3 $MnFe_2O_4$)

Formation of Mn-ferrite,[5] from mixtures of Mn_3O_4 and Fe_2O_3 fired in air, is not a simple reaction. The various phases detected are given in Table II. Reactions that occurred in air are compared with those that occurred in a nitrogen atmosphere. In the nitrogen-fired samples, the constituent oxides are present and unchanged up to the reaction temperature 850°C; the Mn_3O_4 in the air-fired samples undergoes an oxidation to Mn_2O_3 at about 600°C. Before Mn_2O_3 reverts to Mn_3O_4 at higher temperatures (950°C), solid solutions between Fe_2O_3 and Mn_2O_3 are observed. These solid solutions begin to dissociate (below 950°C) into Mn_3O_4 and Fe_2O_3, that is, back to the initial constituent mixture, by a reduction of the Mn_2O_3 part of the solid solution. The dissociated phases Mn_3O_4 and Fe_2O_3 probably still contain small amounts of Fe-ions and Mn-ions respectively. At 1000°C the ferrite formation from Mn_3O_4 and Fe_2O_3 can be represented by:

$$Mn_3O_4 + 3F_2O_3 \rightarrow 3MnFe_2O_4 + \tfrac{1}{2}\ O_2$$

These results, obtained from X-ray diffraction data for both air firing and nitrogen firing, are shown schematically in Fig. 4. The column to the left of each firing cycle represents the major phase at different firing temperatures; columns to the right indicate the minor phases. For the air-fired samples, ferrite formation starts at 1000°C; the nitrogen-fired samples show the first ferrite formation at 850°C. In the air-fired and air-quenched cycle, the presence of a single ferrite phase indicated that the reaction was completed at 1150°C; for the nitrogen-fired sample it was completed at 1250°C. No single ferrite phase material could be obtained when the samples were slow-cooled in air. This was determined by examining the central portion of the ceramic pellet, using X-ray diffraction.

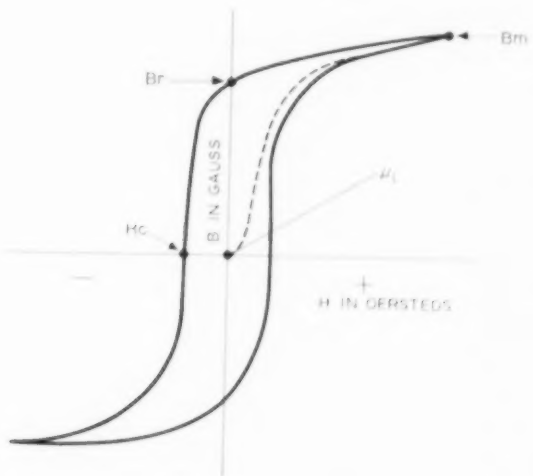


Fig. 10—The d-c hysteresis loop.

During formation of the Mn-ferrite phase, a change of lattice constant is observed which is much more pronounced than it is in the Ni- and NiZn-ferrites. With the exception of the air-fired and slow-cooled sample, the lattice constant is stabilized at about 1400°C, Fig. 6.

Magnetic Hysteresis Loop: The manner in which the magnetization B (in gauss) varies with the applied magnetic field H (in oersteds) for a typical temporary magnetic ferrite sample is shown in Fig. 10. The magnetization curve shown by the dotted line is obtained by subjecting the magnetic material that has not been magnetized before to a gradually increasing magnetizing force H. The magnetization first increases slowly and then more rapidly, and finally approaches a saturation value, B_m. For the initial part at low fields, H, the slope of the curve has been designated as the initial permeability μ_i, frequently employed as a figure of merit when different magnetic materials are compared. The higher the initial permeability is, the greater the likelihood that saturation will be reached at lower fields, H.

If the magnetizing force, H, is gradually reduced from the highest applied value to zero, the magnetization in the material decreases to a value B_r, known as the residual induction. If the magnetizing force is then reversed (by reversing the current in the primary winding) and increased in the negative direction, the magnetization is reduced to zero. At this point, the value of the demagnetizing force is $-H_c$, known as the coercive force. If the field H is varied cyclically between $+H$ and $-H$, a complete hysteresis curve is traced out with no return to the starting point.

Development of Hysteresis Loops: The B-H loops in Figs. 7-9 show the development of the magnetic properties of the three ferrites, as the firing temperature increases during the three firing cycles.

1. Ni-Ferrite (Fig. 7): It is apparent from the hysteresis loops that the three different firing methods applied cause no appreciable difference in the magnetic characteristics. From X-ray diffraction data it was established that the ferrite phase was the major phase present in the reaction product at 1100°C. Since at this firing temperature the crystallite size is small and the body is porous with a distorted lattice, the hysteresis loop is poorly developed. Ordering of the cations, sintering, and recrystallization take place at about 1250°C, where the diffraction line pattern of the ferrite is found to be sharp and is that of a nondistorted cubic lattice. At this temperature development of a characteristic hysteresis loop was also observed. Maximum flux density of the basic Ni-ferrite at a firing temperature at 1400°C is less than 2000 gauss for all three firing conditions; the coercive force is very high, ranging between 7 and 10.

2. NiZn-Ferrite (Fig. 8): At a firing temperature of 1000°C the hysteresis loop is more defined than in the case of Ni-ferrite. This is in agreement with the reaction studies, where it was observed that the beginning of the NiZn-ferrite formation took place at a somewhat lower temperature. The greatest improvement in development of the hysteresis loop can be seen in the sample fired at 1400°C. The maximum flux density appears to be twice as large and

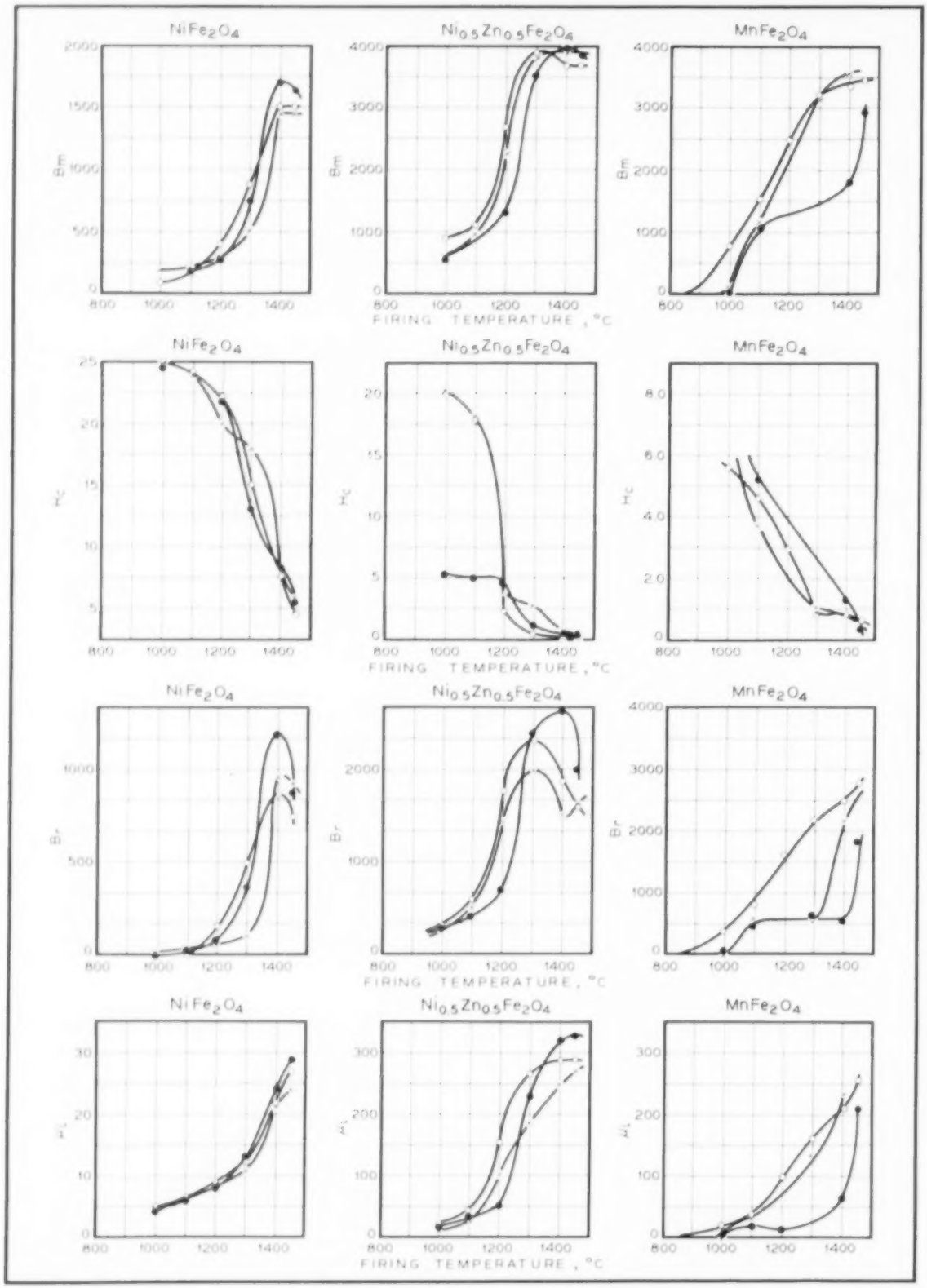


Fig. 11 (top row)—Maximum flux density vs firing temperature. Fig. 12 (second row)—Coercive force vs firing temperature. Fig. 13 (third row)—Residual induction vs firing temperature. Fig. 14 (last row)—Initial permeability vs firing temperature. In each instance crosses indicate air firing with air quenching to RT; solid circles indicate air firing and slow cooling in furnace to RT; and open circles indicate firing in a gaseous N_2 atmosphere with slow cooling in N_2 to RT.

Table III. Comparison of Magnetic Data of Ni-, NiZn, and Mn-Ferrite Prepared Under the Most Favorable Conditions Between 1200° and 1450°C

Ferrite	Firing Temp. °C	B_m Gauss	B_r Gauss	$K = \frac{B_r}{B_m}$	H_c Oersted	μ_i (at 1 KC) 1	Firing Cycle
Ni—	1200	300	80	0.27	22	8.5	Air fired—slow cooled
	1300	750	375	0.50	13.2	13.0	
	1400	1700	1200	0.71	8.2	24.2	
	1450	1630	875	0.54	5.4	29.5	
Ni, Zn— (1:1)	1200	1350	700	0.52	4.6	54.4	Air fired—slow cooled
	1300	3550	2150	0.61	1.2	231	
	1400	4000	2200	0.55	0.37	322	
	1450	3900	2000	0.51	0.36	329	
Mn—	1200	2500	1600	0.64	2.95	100	N_2(g) fired—slow cooled (N_2(g))
	1300	3200	2200	0.68	0.89	160	
	1400	3400	2500	0.74	0.88	210	
	1450	3500	2800	0.80	0.63	260	

the coercive force about ten times as small as that of the basic Ni-ferrite. The air-fired, slow-cooled cycle proved to be the best of the firing conditions.

3. Mn-Ferrite (Fig. 9): The beginning of ferrite formation, as can be seen from the hysteresis loops, is delayed in the air-fired samples. This is in agreement with the solid state reaction studies previously described. The loops differ only slightly in appearance at 1100°C, while at 1400°C the loop of the air-fired, slow-cooled sample differs remarkably from the samples fired in air and quenched and from the samples fired in nitrogen and slow-cooled. This is contrary to results obtained in Ni- and NiZn-ferrite. Maximum flux density is slightly lower than that of NiZn-ferrite, whereas the coercive forces of each are comparable. It can be observed that the Mn-ferrite exhibits a much better rectangular-shaped hysteresis loop than NiZn-ferrite.

Evaluation of Hysteresis Loops: Results of a more detailed evaluation of the loops of these three ferrites are shown in Figs. 11-14, where B_m, H_c, B_r, and μ_i for the three ferrites are plotted as a function of formation temperature. A set of three curves is given for each ferrite corresponding to each of the different firing conditions.

1. Maximum Flux Density B_m: For Ni-ferrite, the optimum B_m for all three firing cycles occurs at 1400°C. The sample that was air-fired and slow-cooled gave the highest value of about 1700 gauss. At a higher firing temperature, the B_m of this sample decreases, perhaps as a result of decomposition and consequent Fe_2O_3 formation. The quenched sample and the nitrogen-fired sample both attain a constant value for B_m of about 1500 gauss and are less sensitive to over-firing. For NiZn-ferrite, with a firing temperature between 1300°and 1400°C, a much higher value for B_m (4000 gauss) is achieved. The effect at 1400°C of the different firing conditions on the magnetic properties of these ferrites is very small. In Mn-ferrite it can be seen that of the three types of fired bodies the nitrogen-fired and the air-fired, air-quenched bodies show the highest B_m values. A maximum flux density of 3500 gauss can be obtained for these bodies, when fired at 1400°C, a value comparable to that obtained from NiZn-ferrite.

2. Coercive Force H_c: The coercive force decreases very rapidly with increasing firing temperature. For Ni-ferrite $H_c = 5$ is attained at 1450°C, and it seems that a further decrease could be obtained at higher temperatures. At about 1400°C the coercive force for NiZn-ferrite reaches a constant value of 0.25, which is twenty times smaller than the value found for the basic Ni-ferrite. At 1450°C H_c for Mn-ferrite has decreased to 0.63, which is about equal for all samples regardless of firing method. For ferrite samples fired in nitrogen at 950°C, the lower value of H_c is found in the case of Mn-ferrite.

3. Residual Induction B_r: B_r varies in the same way as B_m with firing temperature. In Ni-ferrite, the change in B_r is very sharp between 1300°C and 1400°C; the air-fired slow-cooled samples show the largest value of B_r. At temperatures higher than 1400°C B_r decreases rapidly, indicated by flattening of the loop. The maxima of the curves are broader for NiZn-ferrite, which indicates that fluctuations of firing temperature in the 1200°C to 1400°C range are not critical. In Mn-ferrite, B_r is enhanced by firing in a nitrogen atmosphere. When Mn-ferrite is compared with the two other ferrites, no maximum is observed and B_r increases steadily.

4. Initial Permeability μ_i (1kc): Initial permeability increases in the same manner with increasing firing temperature as B_m and B_r. The shapes of the μ_i-curves for Ni-ferrite are very similar; the highest value of 29.5 is obtained with firing in air and slow cooling. NiZn-ferrite shows a maximum value of $\mu_i = 325$, which is one order of magnitude higher than for Ni-ferrite. A maximum value of $\mu_i = 250$ was obtained for Mn-ferrite at 1450°C with firing in a nitrogen atmosphere.

Discussion

Studies of formation of Ni-, NiZn-, and Mn-ferrites from their constituent oxides by solid state reaction reveal that the beginning of ferrite formation, as observed by X-ray diffraction, occurs at temperatures below 1000°C. After firing at 1250°C, the reaction is completed. At this temperature, as determined by magnetic measurements, magnetic property values of all the ferrites fall far short of optimum. Firing temperatures up to 1400°C (Ni, NiZn-ferrite)—and 1450°C or slightly higher (Mn-ferrite) at the favorable firing condition—are required to obtain ferrite materials with the best possible properties. Of the three firing conditions selected in this investigation, the air-fired and slow-cooled cycle is best for synthesis of Ni- and NiZn-ferrite. The best method for the synthesis of Mn-ferrite is the nitrogen-fired, slow-cooled cycle.

Table III summarizes the magnetic data for ferrites, which were prepared under the most favorable conditions. The data given are for four firing temperatures, 1200°C, 1300°C, 1400°C, and 1450°C. It will be seen that the highest values for B_m and B_r (for the firing cycles indicated) are attained at firing temperatures of 1400°, 1400°, and 1450°C (or higher) for Ni-, NiZn-ferrite, and Mn-ferrite, respectively. The values for H_c and μ_i indicate continuous improvement as the firing temperature in-

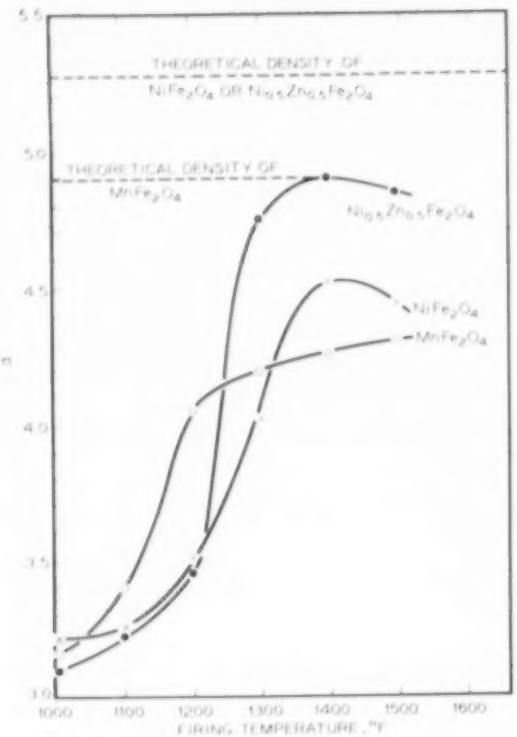


Fig. 15—Density of Ni-, NiZn, and Mn-ferrite as a function of firing temperature.

creases. There might be even further improvement if higher firing temperatures could be obtained. The ration B_r/B_m, which is indicative of the squareness of the hysteresis loops, is included. It is apparent that Mn-ferrite would be the basis of good rectangular-loop material. It is known that this ferrite, when in solid solution with other ferrites (Zn- or Mg-ferrite), shows a nearly perfect rectangular hysteresis loop.

As was demonstrated, the furnace atmosphere can influence the magnetic properties of all these ferrites. Firing in air supports oxidation, while firing in an inert atmosphere, such as nitrogen, supports reduction. In all the magnetic ferrites except magnetite, it is supposed that iron is present in the trivalent state and that reduction would change the valence state from Fe^{+3} to Fe^{+2} (formation of $Fe_3O_4 = FeO \cdot Fe_2O_3$). Oxidation of the Fe-ion to a valence state higher than 3 is questioned. Therefore, with respect to the Fe-ion only, an oxidizing atmosphere such as air would be the most promising. For Ni- or NiZn-ferrite, where any change of the valence state of Ni or Zn in the spinel structure can be considered negligible, air firing and slow cooling would again be the best choice, which was proved by these experiments. In the case of Mn-ferrite, air firing would support oxidation of the Mn-ion resulting in a valence state change for Mn^{+3} to Mn^{+4} (formation of Mn_2O_3 or Mn_3O_4) or Mn^{+4} (less likely at high temperatures). Accordingly, firing in a reducing atmosphere would be required; to maintain the Fe-ions in the +3 state, however, an oxidizing atmosphere would be required. The experimental results prove that prevention of oxidation of the Mn-ion is more important; the nitrogen-fired sample gave the best magnetic properties for the Mn-ferrite bodies.

Density of the fired bodies (Fig. 15) increases rapidly as the firing temperature increases and reaches, for Ni- and NiZn-ferrite, a maximum at about 1400°C; it then slowly decreases owing to decomposition of the material. The density of Mn-ferrite is still increasing at high firing temperature. Under the experimental conditions set up for this investigation, densities of 85 pct, 92 pct, and 87 pct of the theoretical density were obtained for Ni-, NiZn-, and Mn-ferrite, respectively. When Figs. 11-14 are compared with Fig. 15, the density may be observed to change along with the magnetic properties. When density is plotted against magnetic properties for corresponding firing temperatures, there is a nearly linear relationship except in the lowest and highest temperature regions. In the former the reaction is not completed, and in the latter, decomposition in addition to density is affecting the properties. Ideally, ferrites such as Mn, Ni or NiZn contain these cations in the divalent state and iron is in the trivalent state. Departures from these states are considered here as decomposition. As the sintering temperature is increased in ferrites, there is a tendency for the oxygen content to change.[3, 4] Trivalent iron is reduced to divalent iron in magnetite above 1400°C in air. When other cations are present, the tendency toward oxidation will vary. Ferrites have an equilibrium oxygen pressure that usually increases with temperature. Decomposition has been observed at the surface of ceramic pellets of Mn-ferrite.[5] In fact, decomposition of Mn-ferrite also occurs in the bulk, as demonstrated by a change in the lattice constant observed on central portions of the pellets. Mn-ferrite may decompose by either an oxidation or reduction. Chemical analysis should indicate an increase in the presence of either Mn^{+4} or Fe^{+3}. The products in either case will form a solid solution with Mn-ferrite itself. Since lattice constant is sensitive to changes in valence, a change in lattice constant can be expected. The results are qualitatively consistent with the explanation given.

Evidence for the decomposition of Ni- or NiZn-ferrite is demonstrated by the reduction of density and magnetic properties above 1400°C. Ni^{+3} and Fe^{+2} are possible oxidation and reduction products. Vitert[7] and Suchet[8] have both shown that either oxidation or reduction can be inhibited by incorporation of small impurities such as manganese, cobalt, or copper oxide. A more detailed analysis is being made of the property changes with density and crystallite size.

Acknowledgment

The authors are indebted to E. Both for making the magnetic measurements, to G. Slotter for preparing the ferrite toroids, and to J. Mellichamp for performing the spectrochemical analysis.

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Discussion of this paper sent (2 copies) to AIME before Nov. 1, 1957 will appear in AIME *Transactions* Vol. 212, 1958, in JOURNAL OF METALS, October 1958, and in MINING ENGINEERING.

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AIME NEWS

World Metallurgists To Attend Second Annual Congress

The week of November 2 through 8 will be metals industry week in Chicago as metals scientists and engineers from all over the world gather for the Second World Metallurgical Congress, under the sponsorship of ASM. Many of The Metallurgical Society of AIME members are actively participating in preparations for the meeting, under the direction of Zay Jeffries, Battelle Memorial Institute, who is director general of the Congress.

Chicago that week will truly be turned over to metallurgists, since The Metallurgical Society, IMD, will hold its annual fall meeting November 3 through 7, and ISD will hold a one-day technical meeting. ASM's 39th National Metal Exposition will be taking place in the International Amphitheatre.

Some 500 metal scientists from 40 nations are expected to attend the Congress, headquarters for which

(Continued on page 1150)

Steelmen Plan For December Electric Furnace Conference

The 15th Electric Furnace Steel Conference will be held at the Penn-Sheraton Hotel, Pittsburgh, Dec. 4-6, 1957. The Conference will open on Wednesday, December 4, with a plant trip to the Babcock and Wilcox Co., Beaver Falls, Pa. On Thursday, December 5, the morning session will cover the subject of *Nitrogen in Electric Furnace Steel*, a session organized by the Physical Chemistry of Steelmaking Committee. The afternoon session will be on refractories and will cover such topics as rammed or cast center sections on roofs, basic refractories and repairs on sidewalls, tar-dolomite magnesite, furnace bottoms, and ladle refractories.

On the morning of December 6, the Conference will divide into two

(Continued on page 1150)

ISD Plans Sessions During IMD Fall Meeting

Two special sessions covering recent developments in steelmaking practices and continuous steelmaking will supplement the annual Fall Meeting of the Institute of Metals Division.

On Tuesday morning, November 5, recent developments in steelmaking practices will be the session topic, with papers presented on vacuum arc melting, nitrogen control and content of steels, and properties and performance of continuously cast low-carbon steel products. N. J. Grant will conclude the session with a report on the Russian steel industry. In the afternoon, a panel discussion will be held on continuous steelmaking.

Because the meeting is being held in conjunction with the Second World Metallurgical Congress, many European visitors are expected, several of whom will participate in the program, particularly in the symposium prepared by the IMD High-Temperature Alloys Committee. The symposium will concern itself with the relation of structure and high-temperature properties and will be held on Monday morning and afternoon, November 4, and Wednesday afternoon, November 6.

The IMD Committee on Chemistry and Physics of Metals will hold a two-day meeting on Monday and Tuesday, November 4 and 5. The session on Monday will deal with the structure of solid solutions, and Tuesday's meetings will be on the science of alloy hardening.

Also planned for Tuesday, is the Sixth Annual Titanium Symposium. W. J. Harris, Jr., will discuss the progress of titanium in the United States during the past year in the morning session, and, in the afternoon, opinions and ideas on the manufacture and use of titanium will be discussed by a panel with representatives from airframe and aircraft engine manufacturers.

The IMD Nuclear Metallurgy Committee has arranged a full day symposium for Wednesday and this year a fourth day has been added to the overall meeting.

Featured for Thursday, the extra day this year, will be a symposium on Powder Metallurgy with papers on mechanism of sintering in ceramic materials, rate of infiltration of metals, investigation of the effect of specific surface area of certain iron powders on the properties of specimens hot-coined therefrom, high-temperature properties of nickel and cobalt alloy powder extrusions containing nonmetallic dispersions, and the development of superior cobalt-base alloys by hot-coining metal powders with minor additives. Research summaries will be held.

An an experiment this year, papers have been scheduled on the basis of research abstracts submitted up to August 1. Full information on the scheduling of these sessions will appear in the October issue of JOURNAL OF METALS.

This year the featured speaker at the Fellowship Dinner on Tuesday evening will be Professor John A. Wilson of the Oriental Institute, University of Chicago. The meeting will be held at the Morrison Hotel in Chicago.

The Programs Committee of IMD has announced that programming of research papers based on submission of a 200 to 300-word abstract will be continued at the AIME Annual Meeting in February 1958. Authors should submit their abstracts in three (3) copies prior to Nov. 15, 1957, to:

IMD Programs Committee
The Metallurgical Society of AIME
Room 912
29 West 39th Street
New York 18, N. Y.

The abstracts should not include photographs, graphs, or diagrams.

This is the procedure that was followed for the IMD 1957 Fall Meeting and was discussed fully on p. 651 of the May issue, JOURNAL OF METALS.

World Metallurgists

(Continued from page 1149)

will be the Hotel Sherman. During the Congress each foreign delegate will be served by two American counterparts who will serve as a Congress host and scientific associate.

The scientific sessions during the Congress have been planned to cover as broad a view of the metallurgical field as possible from iron and steelmaking to education and trends in research. U. S. metal scientists, 18 in all, have been chosen as moderators of the panels on which about 125 U. S. and foreign experts will probably participate.

Among the panel moderators and subjects chosen, are the following: Charles W. Sherman, Latrobe Steel Co., solidification of steel; Carl E. Swartz, consultant, Hinsdale, Ill., continuous casting; Albert J. Phillips, American Smelting and Refining Co., practical aspects of metal degassing; H. N. Bogart, Ford Motor Co., machining of steel (also co-moderator of panel on testing in product development; R. W. E. Leiter, Budd Co., selection of sheet steel for formability; Robert F. Mehl, Carnegie Institute of Technology, metallurgical education; and Clyde Williams, Battelle Memorial Institute, trends in metallurgical research in America.

Electric Furnace

(Continued from page 1149)

sessions; one, an ingot technical session on *Vacuum Processing of Molten Metals;* the other, a castings technical session on *Foundry Practices.* On Friday afternoon, both groups will join together for a session on *Economic Utilization of Power.* Papers will be presented on power utilization and control in the electric furnace steel plant, effect of the demand limiting system, improvements in arc furnace power regulation, and the study of arc furnace controls.

The Fellowship Dinner will be held on Thursday, December 5, in the Ballroom of the Penn-Sheraton Hotel.

Metallurgy-Ceramics Foundation Planned

A. W. Thornton and David Swan have been appointed as representatives of The Metallurgical Society of AIME on a committee to establish The Metallurgy-Ceramics Foundation.

Authorized by AIME Board of Directors action to be a sponsoring organization to the proposed Foundation, The Metallurgical Society will be joined by ASM, the American Ceramics Soc., and the National Science Teachers Assn.

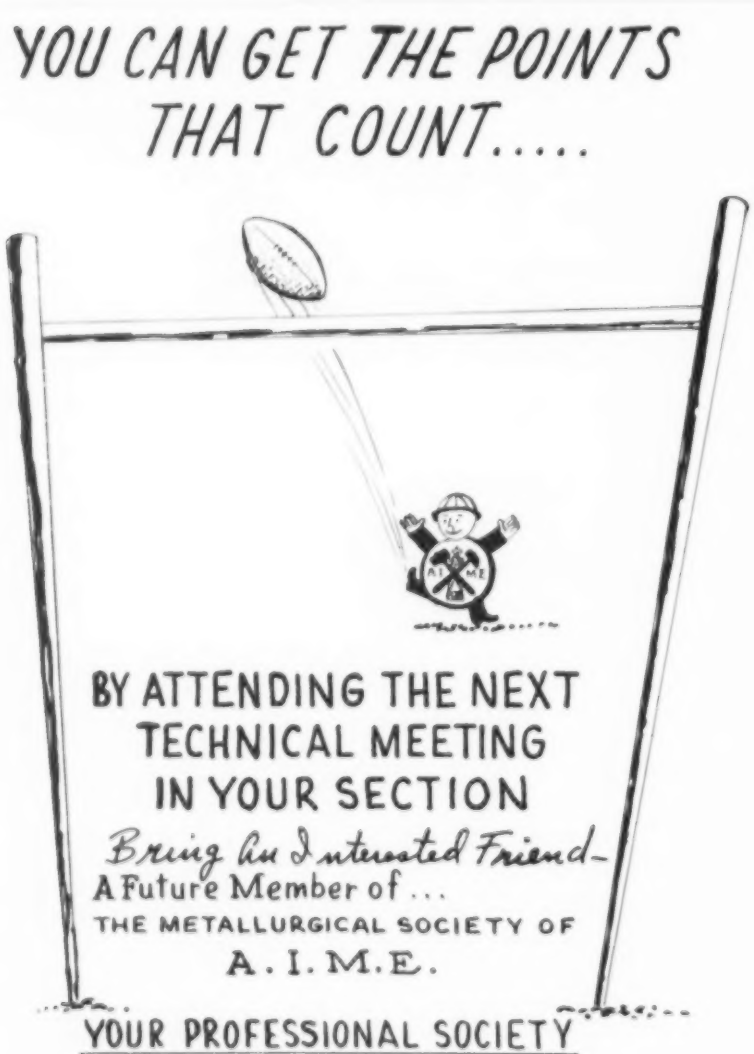
The purpose of the Foundation would be "to carry out, on a continuing basis, a program designed to encourage the enrollment of more and better qualified students in the field of metallurgy, metallurgical engineering, ceramics, or ceramics engineering."

Each of the sponsoring organizations of the Foundation will have two representatives on the organizing committee. The Board of Trustees of The Metallurgy-Ceramics Foundation, once established, would be composed of two members from each of the four sponsoring organizations, two representatives from among scientific and engineering associate groups, and two members from among industrial associate groups.

The Foundation would probably have a small staff of two or more persons to carry out certain programs such as scholarship administration, public relations efforts, etc. The Board of Trustees and staff will try to plan an overall program to cover the interests of sponsoring and associate groups.

The Board and staff would be empowered to raise voluntary contributions in order to carry out its plans, since sponsorship or association with the Foundation will not constitute an obligation to lend financial assistance.

Those connected with the original proposal to establish a foundation such as The Metallurgy-Ceramics Foundation and those associated with the proposal in The Metallurgical Society feel that such an organization can best serve the interests of the groups involved. Other organizations perform vital scholarship functions but do not perform the public relations job many in the engineering profession feel is desperately needed—especially in the fields of metallurgy and ceramics.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THE METALLURGICAL SOCIETY OF
A. I. M. E.
YOUR PROFESSIONAL SOCIETY

Roy T. King Wins Reinartz Scholarship

Roy T. King is the 1957 recipient of the Leo F. Reinartz Scholarship Award at Carnegie Institute of Technology beginning in September 1957. The award represents outstanding achievement in both school and community life.

Mr. King was born in Bolling Green, Ky., in 1940. In 1943 his family moved to Carnegie, Pa., where his father was employed as a lathe operator for the National Supply Co. The National Supply Co. transferred his father to Ambridge, Pa., Spang-Chalfant Div., in 1946.

He attended grammar school at Ambridge, and later attended Ambridge High School where he was among the top ten of the 1957 graduating class of 275 members.

Mr. King has received numerous awards for his participation in his community, among them an award sponsored by the American Legion for a composition entitled *America, One Nation Under God.*

Some of his out-of-school activities include participation in the Aliquippa Community Passion Play and the Aliquippa Civil Defense. He is a member of the Episcopalian Church Choir and a very active member of the Young People's Fellowship. His hobbies include music, hunting, and fishing.

During the summer, he was a counselor at Epworth Woods, Pa., a camp serving underprivileged children from the surrounding area.

METAL INDUSTRY MEETINGS

Oct. 7-9, National Electronics Conference, Hotel Sherman, Chicago.

Oct. 7-12, Societe Francaise de Metallurgie, fall meeting, Paris, France.

Oct. 9-11, Symposium on Vacuum Technology, Hotel Somerset, Boston.

Oct. 15-17, Corrosion Convention and Exhibition, Central Hall, Westminster, and the Royal Horticultural Society's Old Hall, London, England.

Oct. 16-19, Pacific Coast Convention, American Ceramic Soc., Northern California Section, Sheraton-Palace Hotel, San Francisco.

Oct. 17-18, Magnesium Assn., annual convention, Biltmore Hotel, New York.

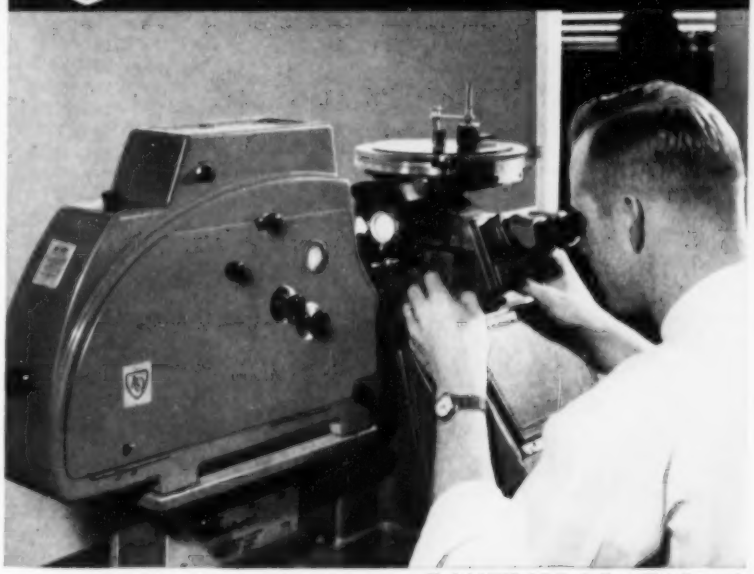
Oct. 28-31, American Nuclear Soc., Henry Hudson Hotel, New York.

December 1957, Indian Inst. of Metals, 11th annual technical session, Bombay, India.

Dec. 1-6, ASME annual meeting, Hotels Statler and Sheraton-McAlpin, New York.

Dec. 8-11, American Inst. of Chemical Engineers, annual meeting, Conrad Hilton Hotel, Chicago.

AO METALLOGRAPHS



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Michaelson Nominated As AIME Director

Stanley D. Michaelson has been chosen to serve as President-Elect of the Society of Mining Engineers of AIME for 1957. He will become President of the Society in 1958 and has been nominated by the Society to serve as an AIME Director for a three-year term, taking office in February 1958.

A native New Yorker, he attended Lehigh University, receiving a B.S. degree in mining engineering in 1934, later doing graduate work there. Although he had done some prospecting in northern Ontario as a student, he began his formal career as a field engineer in the Mining Dept. of Bethlehem Steel Co. Mr. Michaelson was associated for six years with Allis-Chalmers Mfg. Co., first in the minerals research laboratories in Milwaukee, and later as metallurgical engineer and field engineer.

During World War II, Mr. Michaelson served five years in the Army as lieutenant colonel in the Ordnance Dept. Resuming his career after the War, he rejoined Allis-Chalmers as director of the Basic Industries Research Laboratories. In 1947 he joined Tennessee Coal & Iron Div. of U. S. Steel Corp. as a special engineer in the coal mines division. Subsequent promotions led to the position of chief engineer of coal mines and chief engineer—raw materials.

In September 1954, Kennecott Copper Corp. announced Mr. Michaelson's assignment as chief engineer of the Western Mining Divs. with headquarters in Salt Lake City, a post he now holds.

An active AIME member, Mr. Michaelson served as Chairman of Minerals Beneficiation Division in 1954, and in the same year was elected a Director of the Institute. Some of his technical articles were published in MINING TECHNOLOGY and dealt with ball mill and rod mill operations.

News of EDUCATION

► Case Institute of Technology in cooperation with the Lee Wilson Engineering Co. Inc., Cleveland, will present an international symposium on *The Annealing of Low-Carbon Steel* on the Case campus, Cleveland, on October 29 and 30. Purpose of the symposium is to present a critical review of the status of the science and practice of this process. Both U. S. and foreign experts on the subject will meet to discuss the latest developments in the scientific aspects and engineering practice. Sessions will cover basic principles, operational variables and techniques, performance criteria, and economics. These sessions will be so arranged as to permit maximum discussion by the participants. The symposium will conclude with a banquet for delegates.

► The Dept. of Metallurgical Engineering and the Office of Special Services, New York University will sponsor the third annual Titanium Metallurgy Course, September 9 to 13 at the University Heights campus of the University. Open to those with a general engineering background including metallurgy, the course will include 25 lectures by experts in various phases of titanium metallurgy. Dormitory space is available if needed.

AROUND THE SECTIONS

• The **NOHC Southern Ohio Local Section** has announced plans for its fall meeting to be held on October 18 at the Deshler-Hilton Hotel, Columbus. The tentative program will be divided into two sessions, morning and afternoon. The morning session will begin at 10:00 a.m. with chairman P. G. Sammet, Armco Steel Corp., giving a few welcoming words. The session will include a talk given by Leo F. Reinartz, AIME Past-President and consultant, Armco, on the topic *The First Hundred Years of the Steel Industry*. Also on the agenda will be a discussion of *The Revaluation of Charging Layout and Practice* by men from the following steel companies: Acme-Newport, Detroit Steel, and various Armco plants. O. V. Ireland, supervising metallurgist, Armco, and Thomas Schwamburger, general foreman, open hearth, Detroit Steel Corp., will act as presiding chairmen. A luncheon for participants will follow the close of the session.

The afternoon session will include a series of interesting reports which will cover the following subjects: a report on sprung basic roof, tap holes, auxiliary equipment maintenance, instrumentation and maintenance of bath immersion thermocouple, and brick salvage (survey report). The respective speakers will be: C. W. Gravens, Republic Steel Corp., Mac Sample, Armco Steel Corp., Richard Lewry, Detroit Steel Corp.; and Charles Hesselman, Acme-Newport Steel Corp. Presiding as chairman will be Richard Thornberry, Acme-Newport, and T. J. Murray, Armco Steel Corp.

The day's activities will be concluded with dinner at 7:00 p.m. M. F. Yarotsky is tentatively slated to be toastmaster, and the guest speaker will be David Guy Powers of Queens College, New York. Members attending the meeting will have the opportunity to see the Ohio State-Indiana Football game on the following day.

• The research center of International Business Machines Co. at Poughkeepsie, N. Y., will be visited by the **Physical Metallurgy Group,** New York Section, on Wednesday, October 16.

As part of the laboratory tour will be a lecture by L. P. Hunter of the Research Dept. He will discuss projects in metallurgy and ceramics being carried on at the Poughkeepsie laboratories. The laboratory tour will follow with visits to areas where work is progressing on magnetics, transistor studies, and phosphor studies.

After dinner, provided through the courtesy of IBM, Cecil G. Dunn will present a talk on the *Perfection of Primary and Secondary Recrystallization Grains*. Dr. Dunn will describe experiments on Si-Fe by which he obtained data, through the use of dislocation-etch pits, that could be mathematically related to such things as driving force for secondary recrystallization and the critical size of a secondary recrystallization nucleus.

Dr. Dunn, who has been with General Electric Co. since 1937, received the AIME Mathewson Gold Medal in 1952 for his work on grain boundary energy and its dependence on crystal orientation.

Westinghouse Sound Films, **a catalog of 16-mm sound films available free except for shipping charges, lists some 47 general interest, product information, and training motion pictures. Copies of the catalog, booklet B-7077, are available from Westinghouse Electric Corp., P.O. Box 2099, Pittsburgh 30, Pa.**

Energy is Our Business **is a new 16-mm sound color film of 38-min duration, available free except for shipping costs, from the Motion Picture Dept., Westinghouse Electric Corp., 3 Gateway Center, Pittsburgh 30, Pa. Noted actors, John Boles and Arthur Franz, dramatize the story of the fast growing electrical industry. Striking gains in comforts and conveniences enjoyed by the average American family are illustrated.**

Inco's 16-mm film *Ductile Cast Iron* **in sound and color, which runs 16 min, is free upon request from Rothacker Inc., 729 Seventh Ave., New York 19, N. Y. The movie gives details of the development of the new cast iron which is stronger than grey cast iron and so ductile it can be bent and twisted without breaking; its properties and applications are shown.**

PERSONALS

A. L. Spencer has been appointed sales representative for Steel City Testing Machines Inc., Detroit.

George A. Roberts, Vanadium-Alloys Steel Co., Latrobe, Pa., was elected board chairman and president of the Metal Powder Assn., at the annual meeting. Mr. Roberts, as vice president of technology for Vanadium-Alloys, has headed the company's powder metallurgy department since it was first organized shortly after World War II.

John Sullivan of Battelle Memorial Institute, Columbus, Ohio, was honored May 7 with the first Presidential Award of Merit of the American Ceramic Society at their annual meeting in Dallas.

Several employees of the Grand Junction Office, U. S. Atomic Energy Commission, have received cash awards totaling $1,110, in recognition of outstanding work performances and for money-saving suggestions. **Charles A. Rasor,** chief of the ore procurement branch, and **Robert H. Toole,** chief of the leasing and development branch, each won $300.

John F. Hatch has joined Reynolds Metals Co. and will be working in Kwakwani, Rio Berbice, British Guiana.

J. F. B. Jackson, has joined the board of directors of P. I. Castings (Altrincham) Ltd. Mr. Jackson, as former director of the British Steel Castings Research Assn., is a director of A. P. V.—Paramount Ltd., Crawley, England.

R. L. Folkman is now sales engineer at Electro Metallurgical Co., a division of Union Carbide Corp. He will be responsible for the sale of titanium sponge and related products. Since 1951 Mr. Folkman has worked on the development of titanium with the company's Metals Research Laboratories and the Product and Process Development Dept. He will continue to be located at Niagara Falls.

Gerald L. Lee has transferred to the iron and nonferrous castings section of International Nickel Co. Inc.'s Development and Research Div. in New York. He was formerly in the nonferrous section of the company's research laboratory at Bayonne, N. J. Mr. Lee has been with the firm since 1945.

Vernon G. Kneeskern has been promoted to project and plant manager of Reynolds Metals Co.'s newest aluminum reduction plant at Massena, N. Y. He was manager of the Reynolds reduction plant at Longview, Wash.

C. Donald McLain has been promoted to manager, research and development, Western Brass Mills Div., Olin Mathieson Chemical Corp. He will continue his present duties as chief metallurgist in the division, responsible for metallurgical and process engineering at the East Alton, Ill., brass mill.

Albert Muller has been appointed assistant to the president, Air Reduction Sales Co., a division of Air Reduction Co. Inc. Previously Dr. Muller was director of metallurgical research at the parent company's Central Research Laboratories in Murray Hill, N. J.

Raymond A. Quadt has been named director of research and development, Bridgeport Brass Co., Bridgeport, Conn. He will continue as vice president of research and development, Hunter Douglas Aluminum Corp., Riverside, Calif., which was acquired last year by Bridgeport Brass.

Ernest G. Kendall, formerly in the metallurgical engineering department, University of Kentucky at Lexington, has joined Atomics International, Canoga Park, Calif.

Rajendra Kumar completed his studies at the University of Sheffield, England, where he received a Ph.D., and is back in India as lecturer in the Dept. of Metallurgy, Indian Institute of Technology, Kharagpur.

William W. Goshorn, formerly with Sperry-Farragut Co., Bristol, Tenn., has been appointed to the staff of the Inspection Engineering Div., Oak Ridge National Laboratory, Oak Ridge, Tenn.

Edward M. Van Winkle has been appointed general manager of the Magnus Metal Div., National Lead Co., succeeding **John P. Borda,** who has retired. Mr. Van Winkle continues as president of Magnus Metal Corp., a subsidiary of National Lead Co. **John A. Mardick** becomes production manager of the division; **Gibbs C. Merritt** and **George C. Coogan** are assistant production managers; and **John V. Sortor,** comptroller.

New members elected to the executive committee of the Machinery & Allied Products Institute are: **John Lawrence,** president, Joy Mfg. Co., Pittsburgh, and **W. Cordes Snyder, Jr.,** president and chief executive officer, Blaw-Knox Co., Pittsburgh.

The Anaconda Co. has announced that **Edward D. Tierney** was appointed general superintendent, Great Falls Reduction Dept., succeeding the late **Clarence V. Saylor.** Mr. Tierney had been general superintendent of plants, Chile Exploration Co., Chuquicamata, Chile.

Pioneers in the fields of electric furnaces, refractories, gas burners, and protective atmospheres, were awarded the Trinks Industrial Heating Award, highest honor in the industry, at a banquet in the Duquesne Club, Pittsburgh, May 15. Those honored were: **Samuel Arnold 3rd,** consulting engineer, Pittsburgh; **H. M. Christman,** vice president and technical director, Massillon Refractories Co., Massillon, Ohio; **W. Barton Eddison,** consulting engineer, Ardsley-on-Hudson, N. Y.; and **Allen G. Hotchkiss,** manager of furnace engineering, Industrial Heating Dept., General Electric Co., Shelbyville, Ind. The award, bestowed annually by a judges' panel of industrial heating authorities, is named after Willibald Trinks, professor emeritus of Carnegie Institute of Technology, a member of the panel.

James E. Burke was recently appointed manager of alloy and stainless steel sales at the Pittsburgh steel service plant of Joseph T. Ryerson & Son Inc. He was formerly an alloy and stainless steel representative at the company's Chicago plant.

Shadburn Marshall has been appointed director of metallurgical research at Air Reduction's Central Research Laboratories, Murray Hill, N. J.

A. F. Sprankle has been appointed technical director and assistant vice president, Vanadium Corp. of America, New York.

Frank J. Tone, Jr., associated with The Carborundum Co., Niagara Falls, N. Y., for 30 years, has retired as senior vice president. He will continue active participation in the business as a member of the board of directors.

John W. Burlingame, formerly second lieutenant in the U. S. Army Ordnance Corps, has taken a position as metallurgist at Frankford Arsenal, Philadelphia.

Norman Druzbik has accepted a position as metallurgical engineer, Worthington Corp., Buffalo. He graduated in June from Case Institute of Technology, Cleveland.

Robert B. Gordon, previously associated with the School of Mines, Columbia University, is now with the Dept. of Metallurgy, Yale University, New Haven, Conn.

B. R. Queneau, formerly associated with the Duquesne Works, Duquesne, Pa., transferred as assistant manager of metallurgy, inspection, and research, Tennessee Coal & Iron Div., United States Steel Corp., Fairfield, Ala.

J. A. Sisto has been appointed chairman and president of Barium Steel Corp.

Outstanding Young Engineer, **David V. Ragone,** has received the annual award of achievement from the Engineering Society of Detroit. The award was created in 1953 to recog-

nize publicly the high caliber of the young men comprising today's engineering profession. Mr. Ragone is assistant professor of metallurgical engineering, University of Michigan.

Hendrik F. van der Laan has been elected to the newly created post of president of Vitro Rare Metals Co., Canonsburg, Pa. He was formerly vice president and general manager of the Tin Processing Corp.

Thomas H. LeCompte has recently been appointed as sales specialist in the specialty steel and alloy field of the Shieldalloy Corp., Newfield, N. J.

F. A. Green has completed his postgraduate research, and is now employed by the United Kingdom Atomic Authority, Preston, Lawes, England, as a metallurgist in the research and development branch.

C. A. Seger is now employed as a metallurgist at the Carboloy Works, Industrial Products Div., Canadian General Electric Co., Toronto.

George Sachs, professor of metallurgical engineering at the Syracuse University Research Institute, was honored by two German societies, Academy of Technical Sciences and Gesellschaft fuer Metallkunde.

Donald E. Macknight, senior in metallurgical engineering at Montana School of Mines, Butte, has been awarded the Mary W. Young Westervelt Fund loan of $1000 for one year commencing in September. It is one of the sixteen awards presented by the WAAIME to students in all parts of the U. S.

E. A. Eckhardt, geophysicist, has been appointed assistant director of the National Science Foundation for the Div. of Mathematics, Physical, and Engineering Sciences. He previously had been associate director of research at the Gulf Oil Corp.

Oscar T. Marzke, director of research, U. S. Naval Research Laboratory, Washington, D. C., has been appointed vice president in charge of fundamental research, United States Corp. He took up his new post on September 1.

F. M. Hamilton has been transferred to the Cleveland Works, Jones & Laughlin Steel Corp., as sinter plant superintendent, blast furnace department. He had been at Star Lake, N. Y.

The Lake Superior Iron Ore Assn. has changed its name to the American Iron Ore Assn., in recognition of the shift in the last decades of the sources of iron ore. Ore sources, now spread over the U. S. and Canada, were once mostly confined to the Lake Superior district. At the June annual meeting of the group, when the name change was announced, the following officers were elected: **H. C. Jackson,** Pickands Mather & Co., chairman of the board; **F. G. Pardee,** association staff, president; **H. S. Taylor,** Oglebay, Norton & Co., vice president; **W. A. Sterling,** Cleveland-Cliffs Iron Co., vice president; **H. E. Johnson,** association staff, vice president; **A. B. Rathbone,** Oglebay, Norton & Co., treasurer; and **G. E. Guthery,** Oglebay, Norton & Co., assistant treasurer. Newly elected members of the board of directors are: **A. L. Fairley, Jr.,** Shenango Furnace Co.; **G. W. Humphrey; W. S. Moore,** W. S. Moore Co.; **E. H. Winning,** Republic Steel Co.; and **R. T. Elstad,** Oliver Iron Mining Div., U. S. Steel Corp. Re-elected directors were: **R. S. Archibald,** North Range Mining Co.; **P. D. Block, Jr.,** Inland Steel Co.; and **Carl C. Henning,** Jones & Laughlin Steel Corp. Guest speaker at the annual meeting was **Howard Turner,** director of research at J&L.

Charles D. Michaelson, general manager of western mining divisions of Kennecott Copper Corp., Salt Lake City, was among the six distinguished Americans in the minerals industry who received achievement awards at the 83rd annual commencement exercises on May 24 of Colorado School of Mines, Golden.

Robert R. Beebe, formerly with the Dept. of Mineral Dressing, Montana School of Mines, is now with the Brunswick Mining and Smelting Corp. Ltd., Bathhurst, N. B., Canada.

Worthen Bradley, president, Bradley Mining Co. and member of the San Francisco Chamber of Commerce Mining Committee, was a member of the party formed by the committee to take a two-day tour of Northern California mining areas.

W. D. Robertson, previously associate professor at Yale University, has been promoted to full professor of metallurgy.

Lt. Colonel L. G. Klinker has been reassigned by the Army from the post of deputy chief, National Engineering Branch, Industrial Div., Ordnance Ammunition Command, Joliet, Ill., to the U. S. Army Research and Development Liaison Group, Office of the Chief of Research and Development in New York where he will head the Ordnance and Materials Div. of the new European Research Office.

W. P. Morris, executive vice president of the Duval Sulphur and Potash Co., was elected president of the company by the board of directors to succeed the late **George F. Zoffman.**

Hugo Toscano, who has recently received his B.S. degree in metallurgical engineering in this country, has returned to Barrancabermeja, Columbia.

George M. Humphrey, former Secretary of the Treasury, has been elected chairman of the board of the National Steel Corp., Pittsburgh. Prior to entering Government service in 1953, he had been a director and chairman of the executive committee. Mr. Humphrey, who succeeds the late Ernest T. Weir as chairman, was made an Honorary Member of AIME in 1956.

James K. Roros, previously with the Columbia University Engineering Research Center, is now with the U. S. Army Engineer School—Europe.

Marian Balicki has assumed full-time duties as an engineering specialist in the Dept. of Physical Metallurgy and Ceramics at the Sylvania-Corning Nuclear Corp., Bayside, N. Y. He was formerly head, Metallurgical Engineering Div., Polytechnic Institute of Brooklyn.

Clarence Zener, director of the Westinghouse Research Laboratories, lectured at the International School of Physics at Varenna, Lake Como, Italy, this summer.

E. G. Counselman, the Washington representative of H. K. Porter Co. Inc., has been appointed manager of industrial sales with his headquarters in New York. **William E. Haines,** director of Industrial Defense, Dept. of Commerce, will succeed Counselman as Washington representative.

Allison Butts has been selected to serve as a specialist in analysis of materials at the Technical University of Istanbul. Prof. Butts recently retired from the Lehigh University faculty after 41 years of teaching.

Louis A. Carapella was named technical director of the Jessop Steel Co., Washington, Pa.

John C. Fisher, manager of the Physical Metallurgy Section, General Electric Co. Research Laboratory, is returning to full-time research. He is being succeeded as manager by **Roland W. Schmitt.**

Francis J. Shortsleeve has been appointed assistant director of research of the Metals Research Laboratories, Electro Metallurgical Co., Div. of Union Carbon Corp.

Cerro de Pasco Corp., New York, has named **Walter C. Smith** to the position of consulting metallurgist and **Irving L. Barker** to succeed Mr. Smith as resident metallurgist.

James E. Foard, formerly at Douglas, Ariz., has been transferred as smelter metallurgist to the Morenci Branch of Phelps Dodge Corp., Morenci, Ariz.

OBITUARIES

Harold Vinson Flagg

An Appreciation By
Leo F. Reinartz

Harold Vinson Flagg (Member 1948), member Iron and Steel Division of the Metals Branch of AIME since 1948, died on May 28, 1957, at Holy Cross Hospital, Fort Lauderdale, Fla.

He was born Feb. 8, 1893, at East Randolph, N. Y. In 1915, he graduated from Penn State College, majoring in metallurgy.

His first job was at the Briar Hill Blast Furnace and Coke Plant of the Youngstown Sheet and Tube Co.

In 1927, he came to the Armco Steel Corp. in Middletown, Ohio, as a fuel betterment man. He advanced to assistant combustion engineer in 1928, and to combustion engineer in 1929, which was the position he held until his demise.

Mr. Flagg was sent on several technical missions to visit Armco licensees in England and on the continent.

He was a charter member of Armco's technical discussion group in 1930. These discussions have been helpful to young Armco technical and nontechnical men during this entire time.

Many young men passed through his department during the 29 years he was in charge. He was always interested in helping train them. Many have advanced to responsible jobs at Armco.

In addition to his mill work, he was always interested in civic projects, especially being a member of Middletown's Air Pollution Committee. He gave of his time and talents to help improve Armco's Colored Center Clubhouse, and relations with other Armco employes.

He was an active member of the Iron and Steel Engineers. As a member of NOHC for more than 20 years, he presented many papers and discussions, both practical and theoretical, about the use of fuels in open hearth furnaces. He served this committee very well. His advice was sought and readily given for the advancement of the melting technique in the steel industry.

Harold, as he was affectionately known by his many friends in Armco and in the steel industry, was an enthusiastic golfer, bowler, and dancer. He was a member of the Wildwood Golf Club and Forest Hills Club.

He will be missed by those who knew and worked with him over a long period of years.

Conrad F. Nagel, Jr. (Member 1930), died in his home on July 5, 1957. Born in New York, he attended Cornell University. Upon graduation in 1915 he was employed by the Aluminum Co. of America as assistant to the chief chemist. Except for a brief period when he served in the Army in France as an infantry lieutenant in World War I, he remained with Alcoa and in 1952 Mr. Nagel was elected vice president.

George C. Gerner (Member 1920) died on July 17, at the age of 68. He was educated at the Sheffield Scientific School of Yale University and graduated in 1913 with M.E. and Ph.B. degrees. Mr. Gerner was an instructor at the Sheffield Scientific School for three years. In 1916, he took a position with Bridgeport Bros. Co. as a research engineer. He later joined The Miller Co., Meriden, Conn.

Kershaw Harms (Member 1942) died suddenly on July 12, 1957. Born in Salt Lake City, he attended the University of Utah and graduated from the University of Michigan with a B.S. in chemical engineering. He was foreman for the Tintic Standard Mining Co. in Utah in 1921. In 1922 Mr. Harms joined American Smelting & Refining Co., becoming junior metallurgist in 1926. In 1954 he was made general manager of ASARCO's Federated Metals Div. and in April of this year was promoted to vice president in charge of the division.

NECROLOGY

Date Elected	Name	Date of Death
1950	Worth B. Andrews	June 26, 1957
1932	Byron B. Boatright	Unknown
1948	Harold V. Flagg	May 28, 1957
1905	George H. Garrey Legion of Honor	July 23, 1957
1920	George C. Gerner	July 17, 1957
1942	Kershaw Harms	July 12, 1957
1937	Stacy H. Hill	July 7, 1957
1919	John E. Jones	July 1, 1957
1945	Russell L. Kelce	June 30, 1957
1948	Walter C. Kerrigan	July 16, 1957
1920	D. Ford McCormick	July 14, 1957
1917	E. S. McCurdy	July 13, 1957
1930	Conrad F. Nagel, Jr.	July 5, 1957
1936	Oliver J. Neslage	June 19, 1957
1916	Roger W. Straus	July 28, 1957
1935	M. F. Tynan	July 1957
1954	I. H. Wynne	July 11, 1957

MEMBERSHIP

Proposed for Membership
Metallurgical Society of AIME

Total AIME membership on July 31, 1957, was 27,882; in addition 3,107 Student Members were enrolled.

ADMISSIONS COMMITTEE

Harold K. Work, Chairman; Francis B. Foley, T. D. Jones, E. S. Machlin, J. H. Scaff, Paul Von Stein, T. B. Winkler.

The Institute desires to extend its privileges to every person to whom it can be of service, but does not desire as members persons who are unqualified. Institute members are urged to review this list as soon as possible and immediately to inform the Secretary's office if names of people are found who are known to be unqualified for AIME membership.

Members

Robert R. Bowman, Buffalo
J. Duarte-Alvarez, Mexico City, Mexico
R. Russell Fayles, Coatesville, Pa.
Alexander L. Feild, Jr., Wilmington, Del.
William C. Gans, Houston
H. W. Hosking, New Lambton, Australia
E. W. Husemann, Warren, Ohio
Edwin G. Koch, Butte, Mont.
Raymond F. Kunkel, Salt Lake City
Martin G. Kurz, Glen Cove, N. Y.
Chong Lee, Seoul, Korea
Charles G. Mason, Youngstown
A. G. Metcalfe, Park Forest, Ill.
Roger Snellman, Los Angeles
Robert James Stephens, Montgomery, W. Va.

Associate Member

Roland C. Marquart, St. Louis

Junior Members

Rudy E. Clark, Vancouver, Wash.
Edward J. Dunn, Jr., Watertown Arsenal, Mass.
Maurice L. Torti, Jr., Cambridge, Mass.
F. Zahedi, Teheran, Iran

REINSTATEMENT

Member

A. A. Senkowicz, Kasprowicza, Poland

REINSTATEMENT—CHANGE OF STATUS

Associate to Member

J. S. MacNairn, Clawson, Mich.

Junior to Member

Kenneth E. Fisher, Salt Lake City

Student to Member

Thomas A. Prater, Schenectady

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Limited to AIME members, or to companies that have at least one AIME member on their staffs. Rates $40 per year per inch.

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COMING EVENTS

Oct. 3-4, AIME, NOHC Southwestern Local Section, Globe Trotter's Meeting, Shamrock Hotel, Houston.

Oct. 7, AIME, NOHC Chicago Local Section, Phil Smidt's Restaurant, Chicago.

Oct. 11, AIME St. Louis Section, fall field trip to Illinois-Kentucky Fluorspar District.

Oct. 11, AIME, NOHC Eastern Local Section technical meeting, Sheraton Hotel, Philadelphia.

Oct. 11-12, AIME Niagara Frontier Section, meeting and football game, Cornell University, Ithaca, N. Y.

Oct. 16, AIME New York Local Section, Physical Metallurgy Group, plant trip, IBM, Poughkeepsie, N. Y.

Oct. 18-19, AIME, NOHC Southern Ohio Local Section, annual meeting, Deshler-Hilton Hotel, Columbus, Ohio.

Oct. 24-25, EJC, ECPD general assembly, Hotel Statler, New York.

Oct. 30-Nov. 1, AIME Rocky Mountain Minerals Conference, Denver.

Nov. 1, AIME, NOHC Pittsburgh Section, AIME Pittsburgh Section, Engineers' Soc. of Western Pennsylvania, annual Off-the-Record Meeting, Penn-Sheraton Hotel, Pittsburgh.

Nov. 2-8, Second World Metallurgical Congress, Sherman Hotel, Chicago.

Nov. 3-7, AIME, IMD Fall Meeting Morrison Hotel, Chicago.

Nov. 5, AIME, Iron and Steel Division, Technical Sessions, Morrison Hotel, Chicago.

Nov. 12, AIME, NOHC Buffalo Local Section, annual meeting, Royal Connaught Hotel, Hamilton, Ont., Canada.

Nov. 18-21, Conference on Magnetism and Magnetic Materials. Sponsors: AIEE in cooperation with AIME, American Physical Soc., IRE, ONR. Hotel Sheraton-Park, Washington, D. C.

Nov. 20, AIME Niagara Frontier Section, annual Frank J. Tone Award Meeting, Buffalo.

Dec. 4-6, AIME, 15th Electric Furnace Steel Conference, Penn-Sheraton Hotel, Pittsburgh.

Feb. 16-20, 1958, AIME Annual Meeting, Statler and Sheraton-McAlpin Hotels, New York.

Mar. 17-21, EJC Nuclear Congress, International Amphitheatre, Chicago.

Apr. 14-16, AIME, 41st National Open Hearth Steel and Blast Furnace, Coke Oven, and Raw Materials Conference, Hotel Statler, Cleveland.

May 5-6, AIME, Conference on Properties of High-Strength Steel, Penn-Sheraton Hotel, Pittsburgh.

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